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The Use and Application of Photogrammetry for the In-field Documentation of Archaeological Features: Three Case Studies from the Great Plains and Southeastern Alaska

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THE USE AND APPLICATION OF PHOTOGRAMMETRY FOR THE IN-FIELD DOCUMENTATION OF ARCHAEOLOGICAL FEATURES: THREE CASE STUDIES FROM THE GREAT PLAINS AND SOUTHEASTERN ALASKA

By

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THE USE AND APPLICATION OF PHOTOGRAMMETRY FOR THE IN-FIELD DOCUMENTATION OF ARCHAEOLOGICAL FEATURES: THREE CASE STUDIES FROM THE GREAT PLAINS AND SOUTHEASTERN ALASKA

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This master's thesis is comprised of two standalone technical papers united by a common theme. These papers explore the use and adaptation of a new software program, PhotoScan by Agisoft, and the use of non-traditional photogrammetry as a technique that should be incorporated into standard archaeological field practice. The PhotoScan program allows for rapid and accurate capture of photogrammatic information in a multitude of settings. The studies presented in this thesis were conducted between 2013 and 2015, over the course of which multiple advancements have brought the technology to new heights in the streamlined production of 3D representations of features encountered during the course of field study. The methodology was developed while documenting pit hearths in far-western Nebraska, building foundations and other features in south-central Oklahoma, and rock cairns in southeastern Alaska. These diverse environments necessitate different considerations be made, especially in regards to the possible adverse effects to sites. Combined, these studies demonstrate the versatility and ease with which photogrammetry can be adopted as a regular tool for field documentation of archaeological resources.

Acknowledgements

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CHAPTER 1: INTRODUCTION

The documentation of archaeological features has always been a key component of field study. A primary issue in efforts to record these features concerns the dilemma between the degrees of detail desired for individual records versus the limited amounts of field time that can be invested in recording each individual feature. In many instances, the records gained at the point of discovery serve as the sole record with which future analysis and preservation decisions are made. This is especially the case with unobtrusive or remote features that are unlikely to be revisited in the near future. A secondary issue concerns the contrast between the desire to gain information from remains and the desire to preserve the integrity of these remains for future generations. In many instances, archaeological practice is destructive, so prior documentation is the only record that survives analysis. Yet without more intrusive examinations, the research potential of each feature remains under appreciated. Still in other cases, the potential exists for the reconstruction of remains following analysis. Reconstruction thus provides a solution where destructive means can be employed to gain important information, while feature integrity can be maintained, however, efforts must be made to document features beforehand to aid reconstruction efforts while serving to verify correspondence between original and reconstructed forms.

Recently, terrestrial LiDAR and computer automated digital photogrammetry have greatly increased the ease with which archaeological features can be recorded three-dimensionally. With these technologies the dilemmas presented above become less drastic. Terrestrial LiDAR- and to a lesser extent photogrammetry, have been utilized to document, measure and digitally preserve at-risk sites and features. These techniques can be utilized in archaeological contexts ranging from remote locations, to dynamic landscapes, even to full data recovery excavations. These quickly advancing technologies are becoming cheaper and more durable, and are thus beginning to become commonplace in regular field work. This is especially the case with new developments in the technique of photogrammetry, which facilitates a largely automated process based on the use of digital field photos.

Building on the work by Verhoeven (2010), for the adaptation of Agisoft PhotoScan to the use of aerial images, we have used the same software package, albeit heavily updated, with terrestrial based, close-scale photography for the documentation and metric analysis of archaeological features. The advantage this presents is that rather than the need for expensive bulky equipment and specialized crews, the raw data from which the resultant 3D model are derived, consists simply of a series of overlapping images. Though the technique does require a basic familiarity with photography and survey design, the experience required to obtain highly detailed and accurate models is not prohibitive. Furthermore, because the approach can be completed with existing gear (i.e., digital cameras, laptops and desktop computers) ,and because of recent advancements in off-the-shelf highly automated software packages, the approach can be added to regular field methodologies without any substantial increase in monetary or time costs. The resulting 3D models support post-fieldwork visualization, metric analysis, and evaluation for management decisions. They also serve as a base set of measurements for future long-term site monitoring and as primary documents for remote public consumption of heritage through archaeological outreach.

This thesis is organized in the following manner: Chapter 2 presents a case study to demonstrate the suitability of PhotoScan by Agisoft for the in-field documentation of archaeological features through a case study in Alaska. The traditional, paper-centered on research conducted in Alaska demonstrates the basic application of non-traditional photogrammetry in remote locations; where severe weather and a twenty day limitation in field time impacts data collection. Any data collected would be the one chance to collect any data for the project and photogrammetry proved invaluable. Models derived from field images over a three week stay provided detailed 3D representations of cairns. Scaled models of the cairns are used to derive volume estimates and this approach is verified through experimental study. Chapter 3 provides a similar example to the information presented in Chapter 2 but through two case studies in the Great Plains, one in the Oglala National Grasslands and another in Chickasaw National Recreation Area. This case study presents a more comprehensive examination of the PhotoScan methodology and model characteristics and their use for field study and public heritage applications in more traditional cultural resource management projects. Chapter 4 presents the conclusions of this thesis and offers suggestions for future work.

CHAPTER 2:

Photogrammatical Documentation of Rock Cairns in the Tongass National Forest Southeastern Alaska

Presented is a case study in the use of photogrammetry as an aid to field documentation and preservation efforts through the examination of rock cairns situated on a remote mountain side located in the Tongass National Forest in southeastern Alaska. These features represent an ideal situation to highlight the potential of this digital technique as an important addition to standard archaeological field practice. Because the cairns are remote and difficult to reach, little information exists about their function in past society. Additionally, their preservation is at risk because of a lack of communication to the public in general about these features and their importance. Furthermore, because of the difficulty in reaching these locations and the tendency for inclement weather, field time for their documentation is limited and efforts must be made to maximize the amount and quality of data obtained. Thus, the challenges of documenting these largely inaccessible and poorly understood archaeological features–within the time constraints for field study and logistical difficulties their location imposes -present an ideal setting to evaluate the benefits of recent advances in digital photogrammetry and the PhotoScan Pro version program by Agisoft.

Beyond issues of archaeological praxis, there exists the deep cultural connection between these features and the larger Tlingit community who desire to learn about the role of these cairns in their cultural heritage. The detail of photogrammetrical models helps to support more intensive archaeological examination and thus supports this desire, while the ease by which photogrammetrical models can be shared helps to more broadly support access to heritage of this remote region through sharing of 3D representations of archaeological features.

In the study presented below, photogrammetrical techniques are utilized to aid in three primary research goals. First, photogrammetry was utilized as a means of providing detailed 3D representations of features to aid in visualization in both the management/research and public arenas. In this regard, we present various output formats and model quality variations for the models and explore different options for the dissemination of results. The second goal concerns the use of this technique to aid in analysis. Here, scaled models of select cairns were utilized to investigate feature dimensions and to provide measures of 3D volume. These values are compared to infield measures to examine the comparability of traditional versus photogrammetrical approaches. Finally, photogrammetry was utilized as a tool for aiding in excavation efforts centered on the deconstruction and subsequent reconstruction of cairns. This technique provides a detailed base line of the cairn prior to deconstructions and served as a form of quality assurance to verify the quality of reconstruction, while simultaneously serving to aid in ongoing monitoring efforts. Combined, these efforts, serve to highlight the potential of photogrammetry to aid in solving two of the primary conundrums of archaeology: 1. Archaeologists want greater detail in their documentation of heritage features, but lack the time or resource to spend the time required using traditional techniques, and 2. That to gain new information, a resource often has to be destroyed. With these new advancements in photogrammetry and digital curation, and their ability to support detailed reconstruction, this choice may no longer be so conclusive.

Background

Baranof Island Rock Cairns

The study location was centered on a mountain with no official designation, but colloquially referred to as "Cross Peak," on the Duffield Peninsula of northern Baranof Island in the Alexander Archipelago of Southeastern Alaska. The project area is entirely encompassed inside the Tongass National Forest, which, at 17 million acres (69,000 km^2) is the largest national forest in the United States. The region is commonly referred to as the "Alaskan Panhandle," an area of 1,100 islands stretching 300 miles (482 km) north to south. The main islands are the "ABC islands" or Admiralty Island, Baranof (named after the second colonial governor of Russian Alaska, Alexander Baranov) and Chichagof Island (named after Vasili Chichagov a Russian arctic explorer and admiral, who never visited the island.) The islands have a base of basalt centered near the Mount Edgecumbe volcanic field (Riehle 1996) with most elevations in the region residing below 1640 feet (500 m) above median sea level.

Rock cairns are reported in mountainous areas throughout the broader study region and indicate significant human use of these alpine settings, which are known to have been in place by the time of Russian arrival to the region in the 1790s. The Tlingit, who have occupied this region for at least 4,000 years, have little specific knowledge regarding who, when, or why the cairns were constructed. Theories as to the function of rock cairns in general vary greatly from ceremonial (Hartley and Vawser 2007) to hunting related purposes (Binford 1968, 2010a 2010b; Gronnow 2010).

Previously, only eight rock cairns in the Alexander Archipelago (Alexander, Baranof, Chichagof islands) had been recorded. Documented cairns in the study region vary in size but are usually identified facing the interior waterways of the inside passage around the Alexander Archipelago. They are usually identified to be located on benches of the steep mountains overlooking the waterways of the inside passage in the Alexander Archipelago.

In 2006, a team of US Forest Service archaeologists, accompanied a Coast Guard survey team to scout out locations for a proposed radio relay station on top of peaks throughout southeastern Alaska. In the course of the survey, multiple cairns were discovered on Cross Peak. This is the first known official documentation of such rock cairns in southeastern Alaska. These efforts served as the impetus for a pilot program with the goal of finding as much information about the creation, distribution, and possible dating of these prolific features that have been documented throughout southeastern Alaska.

The project, led by William Hunt Jr. and Ralph Hartley involved a team of archaeologists, lichenologists, and oral historians, who, in consultation with the greater Tlingit community, completed research during two separate periods: a preliminary survey in 2010- and a subsequent, larger-sale pilot program in 2013.

In 2010 William Hunt Jr., a National Park Service archaeologist, was escorted by a Coast Guard helicopter crew to the top of an adjacent peak to continue reconnaissance of the area for further undocumented cairns. This brief survey lasted only a few hours but resulted in the discovery and documentation of an additional thirteen cairns. These additional cairns were given the designations Cairn A through Cairn M. A report (Technical Report No. 122) was prepared for the National Park Service. Cairns were usually identified in groups or clusters on benches of mountains facing the water-ways of the interior passage of the Alexander Archipelago, and not facing the Pacific or the interiors of the islands, though this designation or profile may change with subsequent investigations.

For this investigation a cairn was defined as an artificial pile, mound, or stack of stones without a bonding agent. Most cairns are one course high but this may be due to settling from volcanic and earthquake activity in the region and may not be representative of the original height or function of the cairns. Smaller cairns consisting of just a few rocks have also been identified near other cairns of larger size. The findings of this initial report served as the catalyst for the surveys reported here.

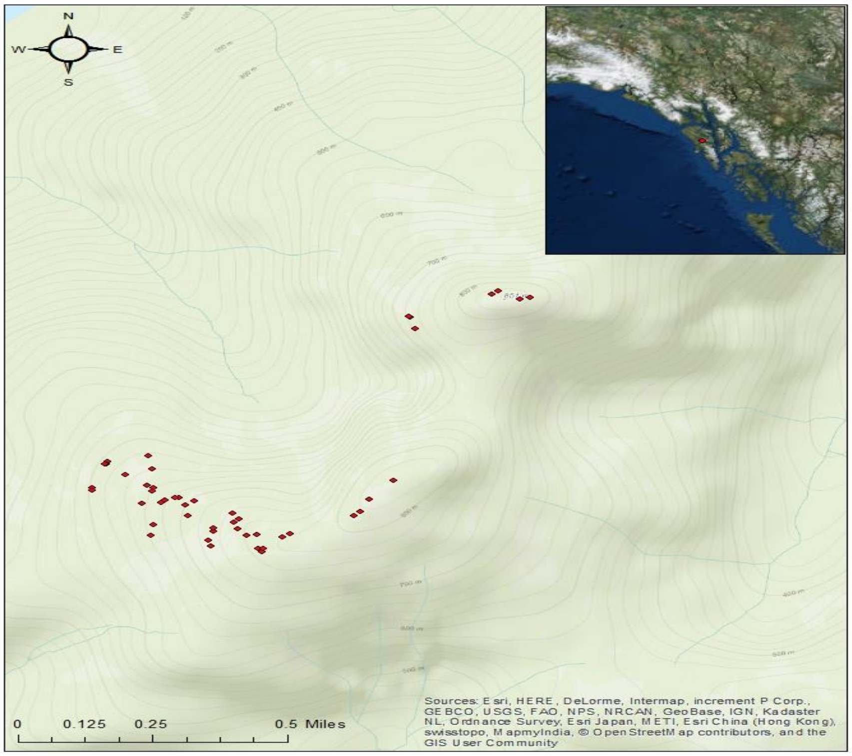

Figure 2-1: Map showing approximate locations of cairns discovered in 2010 and 2013 surveys.

Photogrammetry

Photogrammetry is the science of deriving three-dimensional geometry from photographs. Based on principles of trigonometry, photogrammetry relies on overlapping photographs taken from different locations. These photographs establish different "lines of sight" between each camera point and the object of interest. Through triangulating the intersections of these lines of sight, it is possible to determine the 3D location of the points of interest (Linder 2006). The introduction of computers during the 1960s enabled photogrammetry to perform more precise analytical calculations through the use of computationally intensive numerical solutions and adjustment algorithms (Ghosh 1988;

Schenk 2005). In the 1990s, the advent of digital photographs led to the replacement of film by digital images (Linder 2006). Along with the rapid development of storage device capacities and computational power, photogrammetric calculation is becoming a largely automated process with the capacity to handle large quantities of digital photographic information (Linder 2006; Schenk 2005).

The more recent development of “Structure from Motion” (SfM) approaches further contributed to the expansion of digital photogrammetry software packages available in the last decade. SfM operates by automatically solving the orientation and position of cameras without the need of *a priori* targets with known 3D positions (Fonstad et al. 2013; Westoby et al. 2012). Instead, these parameters are extracted by a redundant and iterative adjustment process that is based on features automatically extracted from large datasets of overlapping images (McCarthy 2014; Snavely 2008; Snavely et al. 2008; Westoby et al. 2012). This approach is suited to situations where images with a high degree of overlap capture the object of interest from multiple positions (Westoby et al. 2012). With minimal manual input, recent photogrammetry software packages are able to automatically orientate camera positions, match features, and generate complex dense 3D models. Since the introduction of these automated programs, studies have applied the photogrammetric technique to the documentation of archaeological sites, landscapes, features, and materials (e.g., Brutto and Meli 2012; De Rue 2012, 2013; Doneus et al. 2011; Ducke et al. 2011; Kersten and Lindstaedt 2012).

The goal of this paper is to demonstrate the utility and simplicity of digital photogrammetry for field survey practices that are commonly employed in Cultural Resource Management (CRM) settings. The introduction of automated photogrammetry packages has opened the possibility for individuals who are less knowledgeable of the technicalities to still apply photogrammetry with sufficient effectiveness. The technique provides an alternative tool that may drastically decrease the amount of field time normally required for traditional documentation techniques, while at the same time providing comprehensive 3D feature models of visual and analytical quality that are equal, if not better, than traditional approaches. The flexibility and manipulability of the 3D outputs also make photogrammetry a useful tool for promoting data sharing, public displays, and outreach. A variety of photogrammetry software packages exist on the market today; from open-source programs to proprietary packages that cost hundreds to a few thousand dollars (e.g., 123DCatch; Bundler; VisualSFM; PhotoScan; Vi3Dim). This study reports on the use of PhotoScan Pro-Edition, developed by Agisoft.

Methods

Survey and Cairn Sample

In 2013, further NSF- supported study was conducted to document rock cairn features on an unnamed peak on Baranof Island in southeastern Alaska. This work served as the basis for a pilot study in the use of photogrammetry for cairn documentation. The remote location and extreme conditions of the study area present a challenge to field research in general and thus represent an ideal setting to examine the potential of photogrammetry as a detailed yet expeditious technique. Time spent in the field was limited to 20 days, but because of rain and other inclement weather, actual field time was limited to 10 days. As a result, field time was severely attenuated and time for detailed, time-consuming, in-field documentation using more traditional approaches was limited. Instead, efforts were made to ensure adequate survey coverage and to complete limited testing (through bisection) of a few cairns in an effort to learn about cairn function and age. This situation, where work was completed under a severe time constraints, presented an ideal setting to investigate how the addition of photogrammetry might be an improvement to more traditional approaches.

The area for the 2013 survey was primarily over 2000 feet above median sea level reaching to 2841 feet at the summit of the unnamed peak which was designated "Cross Peak." A smaller peak, designated "South Peak," is located at approximately 2700 feet (823m) above mean sea level. Pedestrian survey covered approximately 75% of the area above 2000 feet in elevation on the entirety of the Cross and South Peak ridge. This included steep inclines, talus slopes, benches, knobs, snow fields, scree fields, and ridges. Most cairns were discovered to have been built directly over exposed bedrock that made up several prominent benches with western exposure. No associated artifacts were found within or in proximity to the cairns. Two isolated finds of a carbon-battery rod and a .30-30 brass casing were discovered but are not considered to be associated with the construction of the cairns.

Forty-eight total cairns were discovered within the survey area including the 13 previously documented in 2010. Cairns previously recorded were given alphabetic designations A through M, while cairns discovered during the 2013 survey were given numbers starting at Cairn 14 and proceeding to Cairn 48.

All cairns are located on the west facing slope with no cairns discovered on the south, east or north slopes. The west slope directly overlooks a portion of the inside passage. Most cairns are typically constructed of two to three courses or levels of stone measuring, in total, approximately 1 meter high by 1meter long and 1 meter wide; though size, shape, and number of courses varies significantly from cairn to cairn with conical, linear, and U-shaped cairns being documented. In addition to the before-mentioned cairn types, smaller cairns consisting of less than ten rocks placed in circular or semi-circular configurations on prominent boulders or bedrock outcroppings were noted.

All rock cairns were recorded and documented photographically with both digital photographs and in 35mm film. In addition to being photographed, all cairns were GPS located with a Trimble GPS unit utilizing Terra Sync software to allow for direct input into GIS software and shape file base maps. The Trimble was connected to the Wide-Area Augmentation System or WAAS, and capable of sub-meter accuracy and was able to achieve this level of accuracy for most cairn locations.

Photogrammetry Methodology

Photographs for the purposes of photogrammetrical reconstruction were taken for Cairns A, G, H, I, and L from the 2010 survey. For this study, we used a Canon Rebel Xsi digital SLR camera with an EF-S 18-55mm zoom lens and a Nikon Cool Pix, 14 megapixel digital camera with a 4.6-23.0mm lens. Images were then processed using the PhotoScan software package developed by Agisoft LLC (AgiSoft LLC 2014a: iv). The software operates on Windows systems and utilizes a wide range of image file types (JPEG, TIFF, PNG, BMP, and MPO) to create 3D meshes and textures. A discussion of the photogrammetrical process from image acquisition to the production of completed models follows below.

Image Acquisition

Feature photography is the only stage of the process that necessarily takes place in the field. This step is executed by gathering a series of conventional photographs taken with standard digital cameras and lenses and requires that photos of the target object are taken from different vantage positions, thus allowing the reconstruction of geometry. Most of the models generated in this study were produced from between fifty and two-hundred photographs.

Under ideal conditions, strong shadows and contrasting light should be avoided during the image acquisition process. However, due to the brevity of the field project and limited potential for a revisit, photogrammetrical documentation for this study was completed as features were encountered, and satisfactory models were obtained even under the dark and rainy conditions of Baranof. Another aspect to consider is the influence of obstructing objects and other elements that may create variance in the scene between shots. These include moving objects such as blowing grasses and brush, clouds, or members of the field crew, and reflective surfaces or wet surfaces. The use of flash can also create inconsistency in the lighting among photographs.

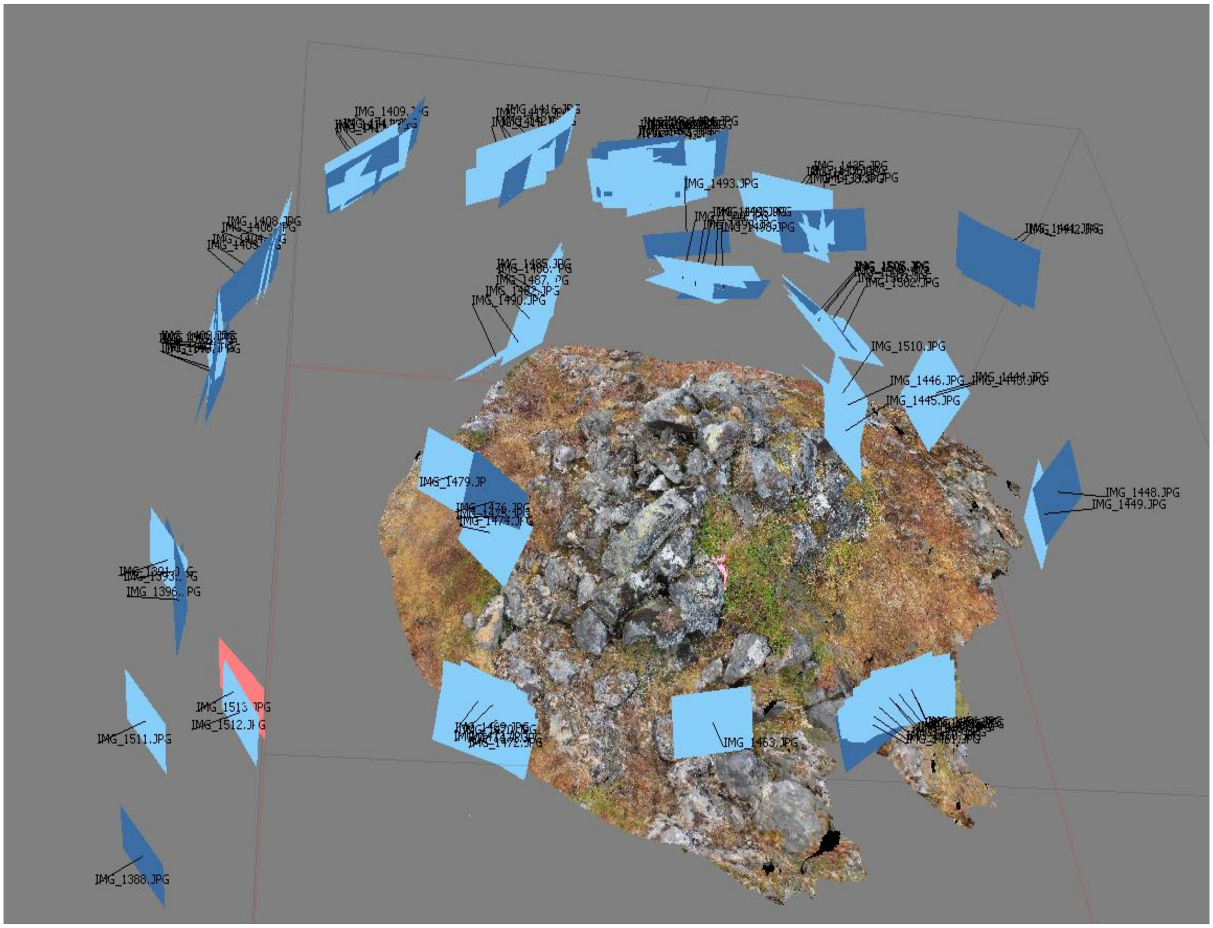

Figure 2-2: Model generation showing camera alignment and saturation during photography of the feature. (Note Duplicate Camera Positions can be deleted during Model Processing).

In the case of cairn features, individual cameras should be positioned around the feature with converging vantages to ensure coverage of all surfaces as depicted in Figure 2-2. Photographs were taken at an equal distance removed from the cairns with the camera set for a large focus setting such as “Landscape.” This setting gave the best clarity and focus for the entirety of the cairn. The cairns were then circum- navigated and photographed at intervals, determined by pace count, avoiding hazards, and achieving saturation of the subject, with the goal being to ensure sufficient overlap in photos to enable proper model reconstruction.

The process outlined above was completed for five cairns. Additionally, cairns A and G were selected for deconstruction to support more detailed examination. A first series of photos was taken of the undisturbed cairn. Each cairn was then bisected with subsequent images being completed at each step of the bisection process to create a model of the cairn before, during, and after. These models serve to document the process and demonstrate the quality of reconstructions to the Tlingit community who expressed a desire for accurate reconstruction of the cairns.

Model Building and Output

After the process of collecting the photographs in the field is complete, the images are downloaded onto a computer equipped with PhotoScan. Next, the photographs are sorted by individual cairn into separate folders for ease of viewing. The photographs are then sorted further to determine which ones will work best to render a model by dismissing all faulty or blurred images. Unwanted objects within an image (e.g., field equipment or field crew members) can be removed from the active scene using the masking function. The designers of PhotoScan strongly recommended that photo editing software such as Photoshop, not be used to edit any of the images to be used in model generation. This is because PhotoScan makes use of the metadata held within the photograph file and thus relies on a correspondence between metadata and the image used in the model building process.

The next step consists of aligning the images to reconstruct the three-dimensional scene. This process is based on matching points from the series of images and is the primary basis through which 3D geometry is established and results in the creation of a sparse point cloud. The next step is building a dense point cloud, which offers more data points for reference to complete the model. A wire frame model or mesh, is then generated from the point cloud by creating polygons from the points.

An optional final step creates a textured model using a photographic overlay. This final step can be completed using a variety of options (e.g., multiple or single images and averaged or mosaic settings) and gives the completed model a photorealistic quality. For the cairn project, all settings used in model generation are the base settings provided by PhotoScan for ease of processing. Other programs independent of PhotoScan including Meshlab, GeoMagic, Python, Photoshop and Gimp may be used to help in this process but are not required.

For processing multiple subjects and "chunks" simultaneously, batch processing may be used. This option was utilized for the models run for the volume calculation experimental proof of concept (see below). This process allows for multiple models to be produced step-by-step at the same time thus reducing the need to manually advance the PhotoScan process for each model.

The rendered PhotoScan model can be output in a variety of formats (e.g., .obj and .plz) and can also be converted into a decimated 3D PDF type document file for easy dissemination. The use of PDF (Fig. 2-3) is an important option because other output formats are not easily read without a PhotoScan license of similar software and the file size of the decimated PDF is often small enough to be easily shared through email or other file sharing options (e.g., Drop Box, Google Drive). Within the PDF document, the model is still movable within the frame on three axes with full rotation as well. Converting the model into a PDF document opens new features that 3D PDFs offer including zooming in and changing the background and model colors to higher contrasts, or to show all vertices of the wire frame model. It is also possible to view the model under different lighting conditions in order to view objects embedded in the model that may not show up at that angle under standard conditions.

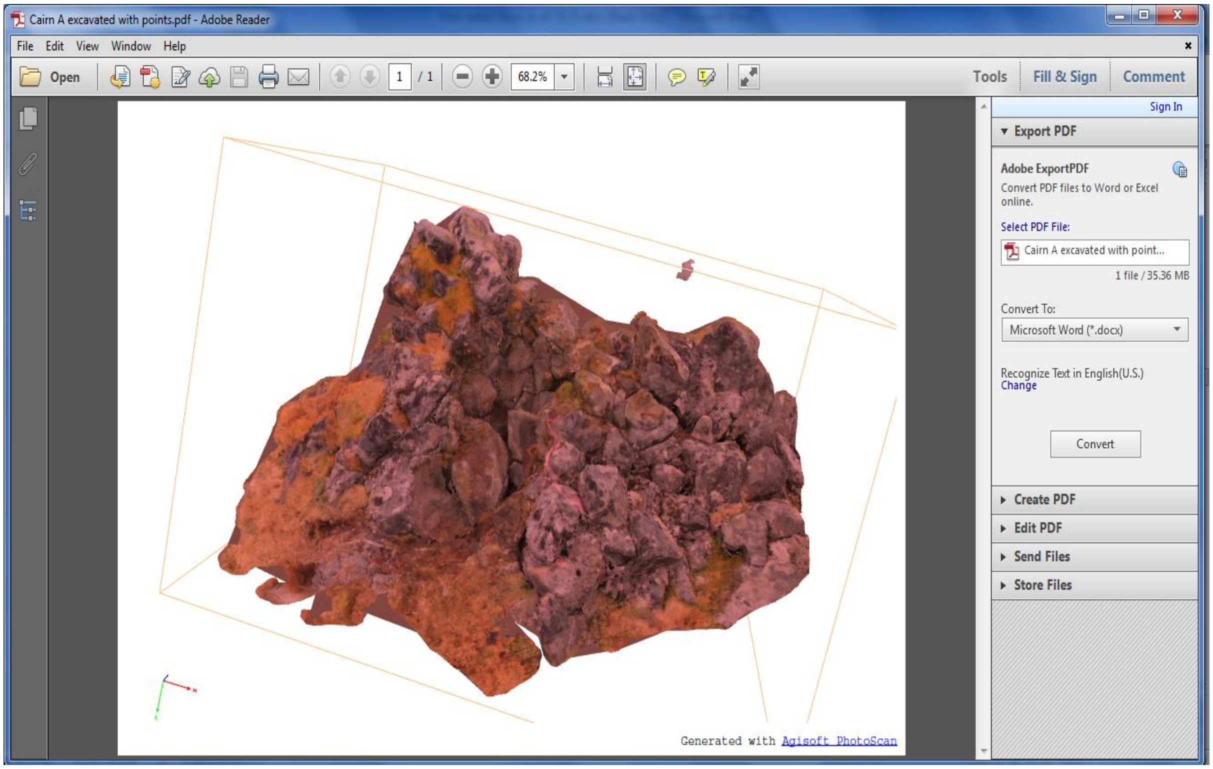

Figure 2-3: Screen Capture of3D PDF of Alaskan Cairn A. These PDF's are easily shared by email and file sharing sites and are fully manipulatable in 3D (i.e., rotation, zoom function, and various viewing options) using standard Adobe Reader.

Scaled Models and Metric Analysis

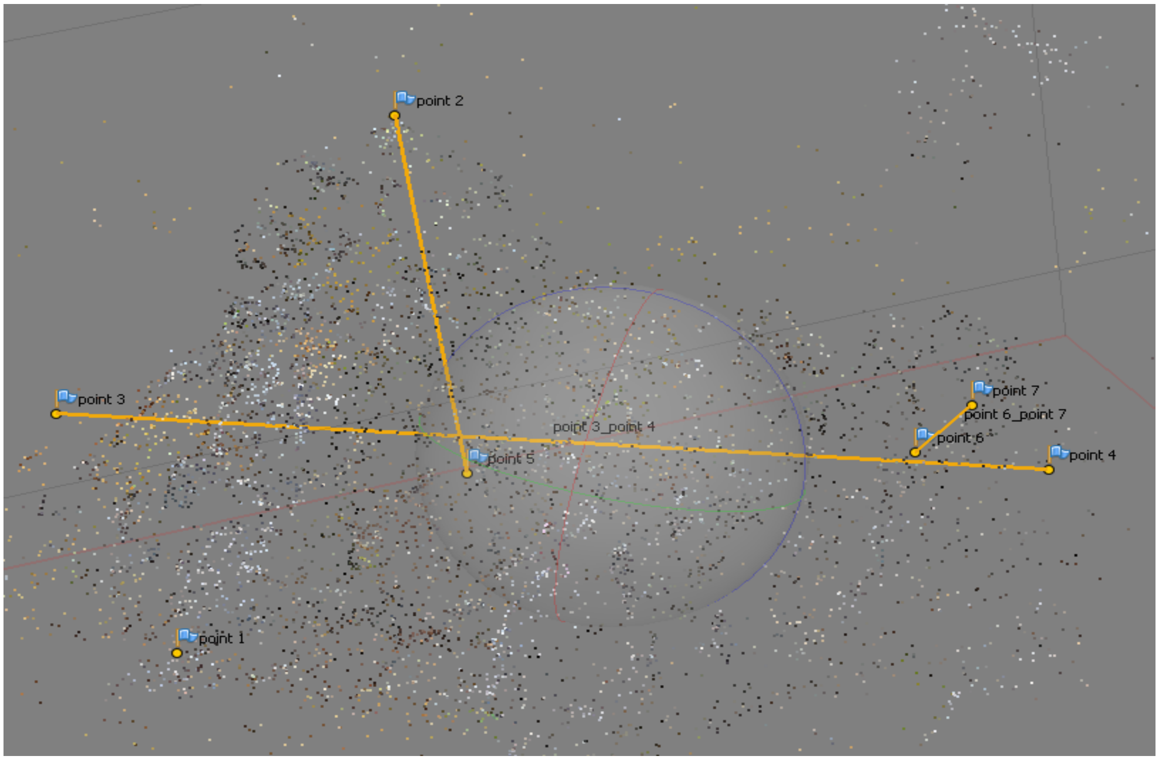

Figure 2-4: Image of PhotoScan point-to-point measurement for a dense point cloud of one of the Alaskan cairns. Markers are placed on two locations of known distance to scale the model. Once scale additional markers can be positioned to complete further measurement within the model.

For this study, Agisoft's PhotoScan Pro-Edition was utilized as this version of the software includes additional model editing tools and the ability to scale and calculate volume (features not included in the standard version). Here scaling is completed by placing a scale bar in the scene of interest or by manually measuring the distance between points that can later be identified in the completed models. In the completed model, 'markers' are then placed at appropriate locations and the measured distance is then manually input into the software (Figure2-4; and Fig. 2-5).

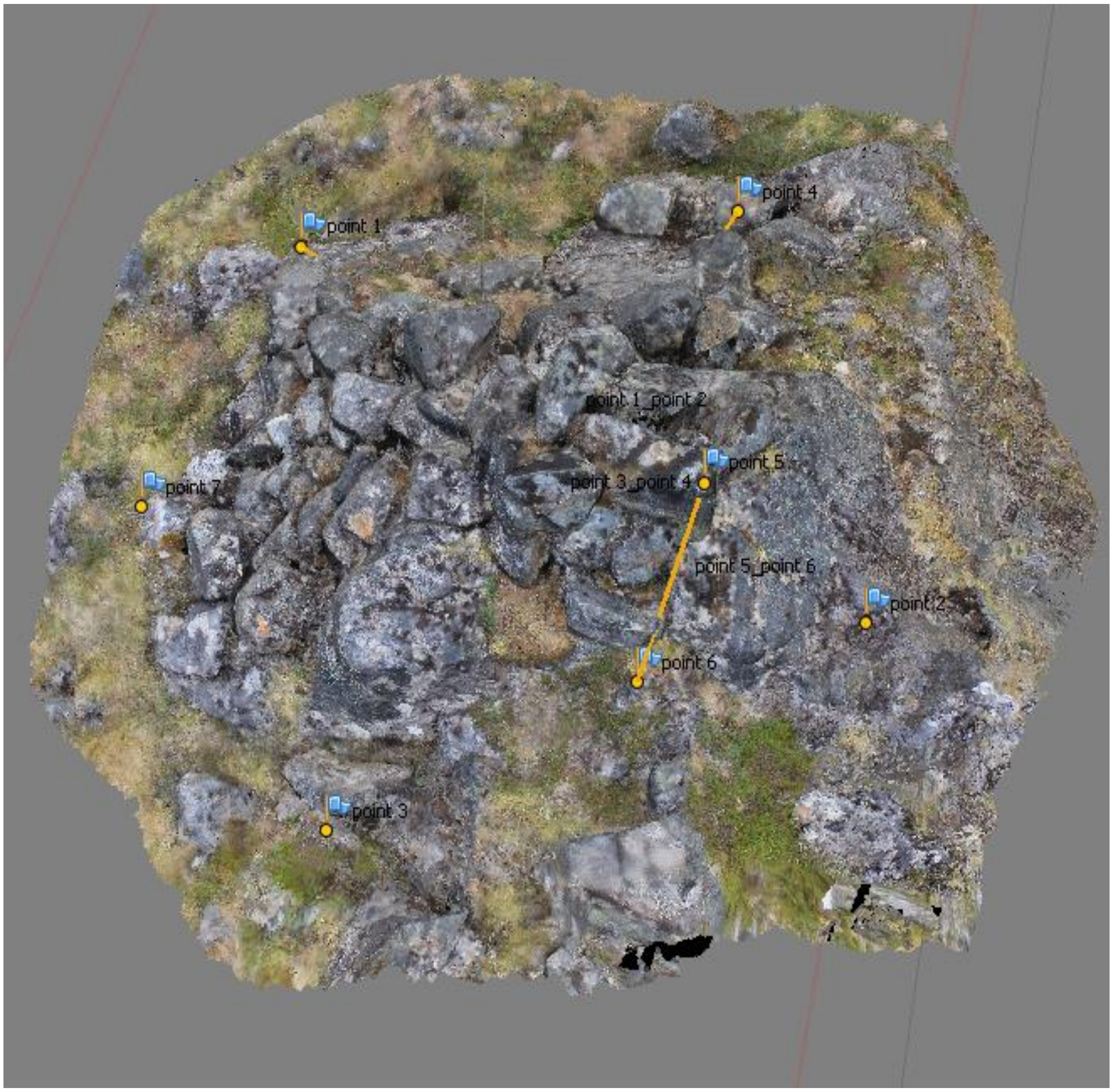

Figure 2-5: Example of scale bar in model on known distance.

This allows measurements of individual elements in the completed model as well as the calculation of surface area and volume. Other forms of shape analysis within the scaled models can be completed with exported models using software such as the professional engineering software Geomagic, or the open source equivalent MeshLab, developed by ISTI-CNR. Plan view orthophotos of the scaled models can also be saved within the PhotoScan environment. This option allows scaled 2D representations suitable for measurement in printed form (e.g., additional measurements can be made from printed reports using this setting).

Experimental Proof of Concept

A goal of the project was to develop scaled models of the cairns to complete subsequent analyses including the measurement of cairn volume. Volumes derived using the PhotoScan process were thought likely to be more accurate that more traditional measures completed in the field using pull tapes and thus of value for the more detailed recording of these understudied features. To test the ability of PhotoScan to provide accurate measurement of cairn volume, an experimental proof of concept was conducted in a laboratory setting at the University of Nebraska-Lincoln. Here three scaled rock cairns were constructed using a random sampling of quartzite cobbles. The volume of each cobble used in the construction of the experimental cairns was calculated by dividing its weight by the specific density of quartzite (2.6; edumine). For the purpose of this study, measurements obtained from specific density were held as “true” and thus served as the known value for comparison with photogrammetrical measurements. Individual cobbles were then assigned to one of three groups with the three cobble groups being used to construct cairns of varying shape. These cairns of known volume (as based on the measures of each cobble from which they were constructed) were then documented using the same photogrammetry methods as utilized during the field component of this project (Figures 2-6 through 2-8). Additional measurements between observed landmarks on the experimental cairns (i.e., distances used to replicate the field measurements of length, width, and height completed for the archaeological cairns) were then recorded. Combined, ‘true’ values of volume and basic size measurement for the experimental cairns were thus available for comparison to the same measures as completed through photogrammetry.

Figure 2-6: Traditional photograph of Concept Cairn 1.

Figure 2-7: Traditional photograph of Concept Cairn 2.

Figure 2-8 Traditional photograph of Concept Cairn 3

The pictures of the experimental cairns were then loaded into PhotoScan and models were produced (Figure 2-9) using a single scale bar to scale each model as described previously. To produce models suitable for volumetric analysis, the cairn bases were ‘closed’ to produce sound models using the “close holes” feature in PhotoScan. This process allows gaps in photographic information- such as the bottom of a cairn where it would be impossible to photograph, to have known model points on corresponding facets to be connected with no visual information added.

Figure 2-9: Examples of the experimental cairn models produced through photogrammetry.

The scale bars in the photographs were used as land marks in the models and marked in PhotoScanto obtain known distances for scaling of the model. Comparison of measures of cairn dimensions (i.e., length, width, and height) and the physical measurements taken in the laboratory are presented in Table 2-1. These comparisons demonstrate the close agreement between model and field measurements and thus support the use of PhotoScan models for the completion of subsequent post-field measurement. The scaled PhotoScan models also allowed the calculation of volume that could then be compared to known values as determined through specific gravity. While this would give a test of the accuracy of volumes derived from 3D representations of the experimental cairns, the purpose of the experiment was not only to demonstrate the accuracy of photogrammetry but also to evaluate its utility as an alternative to existing field methodologies.

Cairn	**Measurement One**	**Measurement One Model**	**Measurement Two**	**Measurement Two Model**	**Measurement Three**	**Measurement Three Model**
1	**30.48cm**	**29.63cm**	**02.54cm**	**02.37cm**	**.07cm**	**07.21cm**
2	**30.48cm**	**30.68cm**	**0.80cm**	**07.60cm**	**.05cm**	**04.99cm**
3	**30.48cm**	**29.80cm**	**0.60cm**	**05.68cm**	**.06cm**	**05.49cm**

Table 2-1: Comparison of physical measurements to those completed in PhotoScan for the Concept Cairns.

As a point of comparison, a tape measure was used to replicate the field measurements. Here cairn dimensions of length, width and height were obtained in a fashion similar to that of a field crew pulling and draping tapes within the course of field survey. Table 2-2 shows the contrast between measures made from the models and those use to replicate field protocols.

Cairn	**Length**	**Model Length**	**Width**	**Model Width**	**Height**	**Model Height**
1	**25.0cm**	**26.7cm**	**22.0cm**	**24.3cm**	**18.0cm**	**17.5cm**
2	**40.0cm**	**44.0cm**	**27.0cm**	**28.2cm**	**21.0cm**	**21.1cm**
3	**30.0cm**	**32.0cm**	**29.0cm**	**30.0cm**	**15.0cm**	**11.3cm**

Table 2-2: Compares Physical Measurements comparable to field methodology to those completed in PhotoScan for the Experimental Cairns.

To provide this comparison, the use of the measured length, width and height measurements physically obtained from the experimental cairns were then used to calculate volume using a number of different geometric formulas. This approach, based on the use of field measurement and solid geometry, is the current standard in most volume estimates of built features (e.g., Bernardini 2004 for mounds; Jeter 1984).

Table 2-3 compares model derived measurements of volume to those obtained through specific density and the use of field measures and solid geometry.

Cairn	***lwh* *(cube)***	**1/3πr²*h* *(cone)***	**2/3πr³ *(hemisphere)***	***Specific gravity***	***Agisoft***
1	**9900.00**	**2602.42**	**3397.61**	**2921.50**	**3086.10**
2	**22680.00**	**6169.89**	**9842.45**	**4810.00**	**4898.37**
3	**13050.00**	**3417.46**	**6721.01**	**2707.00**	**2689.91**

Table 2-3: Comparison of volume measurements derived from geometric models, specific gravity estimates and PhotoScan.

Results based on the use of different geometric equations show broad variability and thus the broad error range likely to be encountered as real world objects are approximated by different geometric solids. The comparison between PhotoScan derived measures and those obtained through specific gravity, however, demonstrates close agreement and thus support the observation that photogrammetry offers a superior means of measuring volume for the Alaskan cairns. When compared to volume derived from specific gravity, the photometric volume proved to be more accurate than traditional field method for measuring and calculating the volume of rock cairns.

***Archaeological Results*.**

Cairns A, G, I, L from the 2010 survey and cairn 49SIT737 from the 2007 survey were extensively documented to pilot the use of photogrammetry for cairn documentation. Of those cairns, A and G, were deconstructed and models were created to record the cairn characteristic at points before, after deconstruction, and after reconstruction. Most of the cairns selected for intensive photogrammetry documentation were from the 2010 survey due to the more pronounced nature of the features on the landscape, in fact, they were originally identified by helicopter.

Visualization

Three-dimensional models can be made through photogrammetry expediently in the field and offer a novel and cost-effective medium to document features in extreme environments. The resulting models can be displayed in a variety of formats. Figures 2-10 presents mesh and textured image models for cairn G while figure 2-11 presents various visual formats produced throughout model generation ranging from a sparse point cloud through to the image textured model for cairn I. These models provide sufficient detail to examine various elements of each cairn including individual stones and the ability to fully rotate each model allows its examination from all possible angles. These aspects of the models will help to support detailed post field evaluation of cairn construction methods and other cairn characteristics (e.g., stone shape and size, number of courses, general cairn shape).

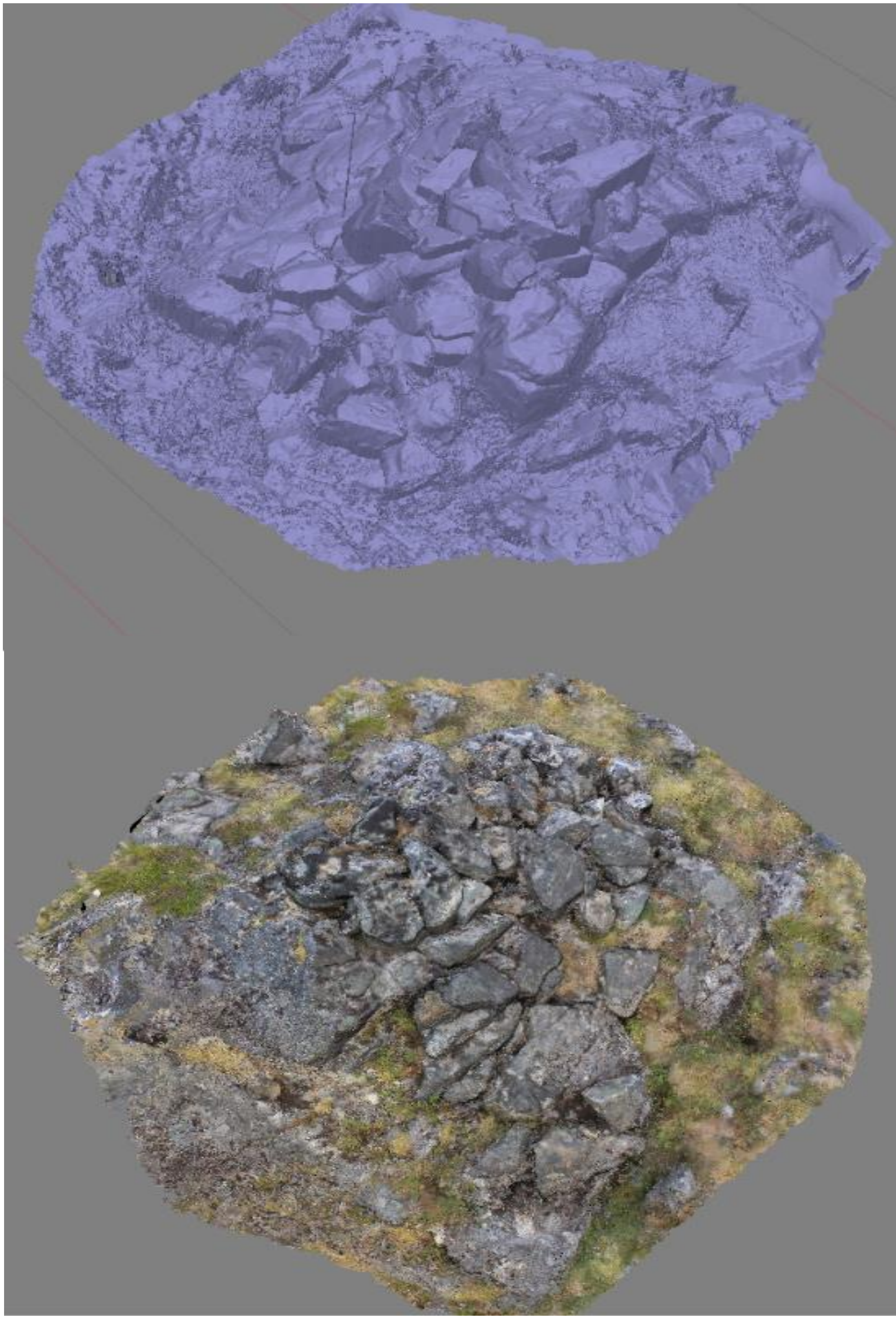

Figure 2-10: Example of Mesh and Image textured model.

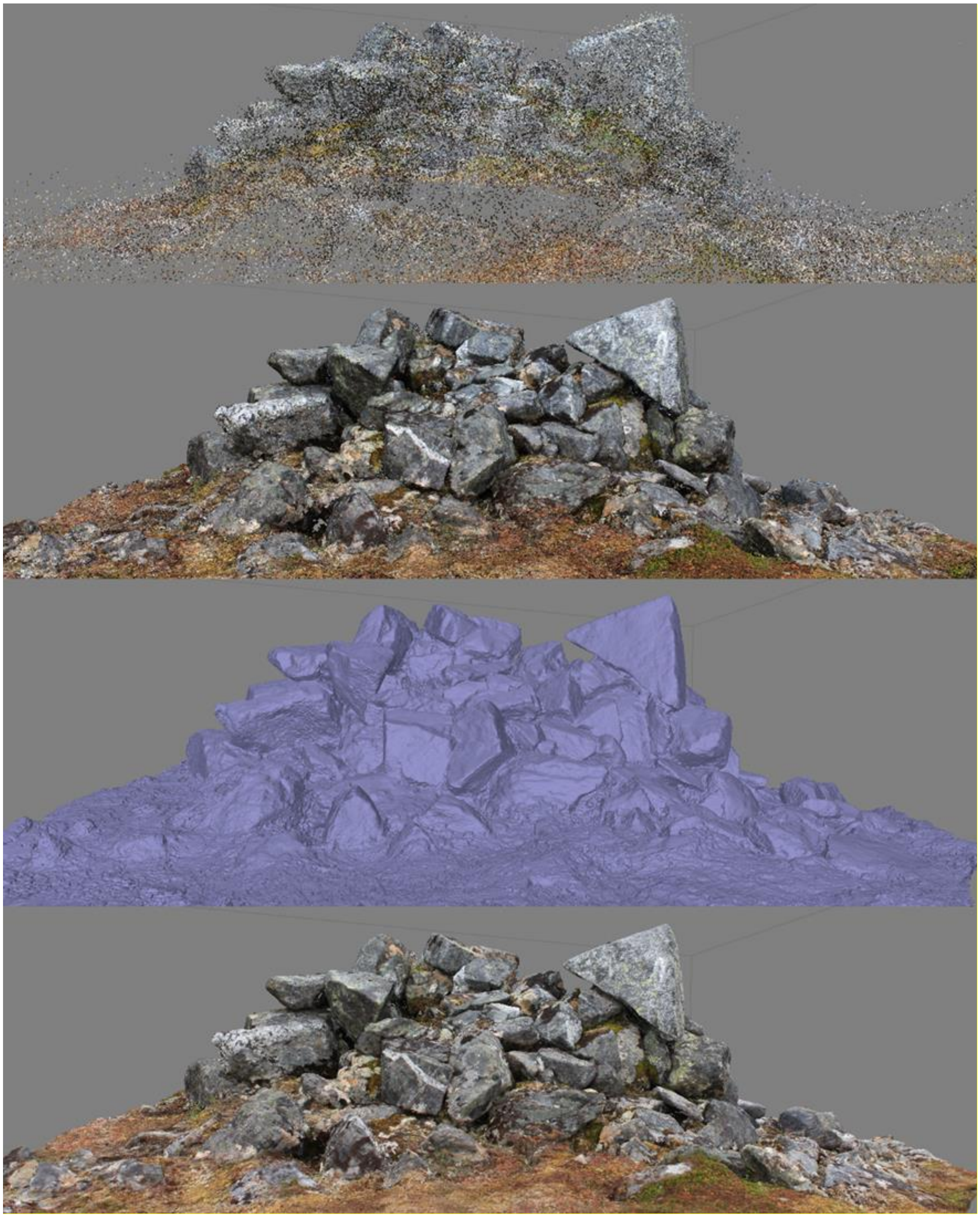

Figure 2-11: Finished Model of Cairn I from Baranof Island Displayed in Different Model Formats (from top to bottom, the sparse point cloud, the dense point cloud, the solid mesh, and the image texture mesh).

The quality and versatility of the models is far superior to sketch maps or the information that can be recorded through individual photos and could be made greater with refinement of the approach utilized in this pilot study. The quality of the photos obtained in the field, and thus the detail in the resulting models, is a consequence of the type of camera used. In this case, an older field grade 10 MP SLR camera, already on hand was used. A newer camera with a better sensor (i.e., higher megapixel count and higher resolution) would produce finder details in both the model mesh and image overlay and will be adopted for future study. The use of DGPS to establish ground control points would also support greater refinement in image alignment which can help to provide further clarity in model elements. These are all improvements that can be suggested following this pilot study.

Because of the limited time investment both in the field and during post processing, the approach can be readily incorporated into regular survey routines and can be completed without the need for extensive training. The use of both Mesh and Image texture models could also serve as a baselines for monitoring cairn preservation through time.

Output formats for the models also support file sharing for research and outreach. In the case of the cairns, PDF files of the cairn models generally range in size from 10-100 MB and can thus be shared via email and file sharing such as Drop Box. These fully interactive, decimated models makes for easy correspondence between project team members, land management agencies, and the Tlingit community. Models can also be made available through online hosting sites, such as Sketchfab (sketchfab.com), which supports full viewing of models and file download. (Free for 50MB or less with various options available for large files). Because these are available online, broader professional and community access can be made available and model links can be shared via social media (e.g., Facebook) as well as project websites. These various options enable a variety of audiences to visualize cairns for both education and research purposes.

Beyond the abilities of this approach as a tool for archaeological research, it also has the potential to increase public outreach through interaction with interpretive displays and report results, thus increasing stewardship and awareness of archaeological resources that are threatened or endangered due to degradation. In the case of the Alaskan cairns, these cairns are important to the local Tlingit community, but the remote location of these features means they are not readily accessible. The models via these various sharing options, however, can be brought to the community.

Scaled Models

A comparison of field measurements to those obtained with the scaled cairn models provides another examination of the utility of photogrammetry (Tables 2-4 and 2-5). Given the performance of photogrammetry in the experimental test presented above, differences between field measurements (made with pull tapes) and those obtained from the scaled model are almost certainly due to error or imprecision in the field measurements. The accuracy of the scaled models for model measurement shows another benefit of photogrammetry. Not only can measurements be used to refine field measurements, but also other measures on individual features (e.g., individual stone size, cobble shape proportions) can be made for further analysis. This supports ongoing study and the investigation of aspects of cairns not addressed in initial research design, which is especially useful in this study due to the limited imposed by the attenuated field season.

Cairns	**Field Height**	**Model Height**	**Field Length**	**Model Length**	**Field Width**	**Model Width**
737	1.4m	.81m	1.2m	1.2m	0.7m	1.03m
A	0.8m	0.89m	3.3m	3.3m	2.7m	2.9m
G	0.9m	1.4m	3.0m	3.1m	2.9m	2.4m
I	0.8m	.88m	2.1m	1.9m	1.5m	1.6m
L	0.8m	.79m	1.7m	1.5m	1.2m	1.2m

Table 2-4: Comparison of field measurements and PhotoScan derived measurements

The scaled models were also used to calculate volume from the cairn models and these were compared to the types of volume estimates that would come through the use of field measurements and geometric formulas. Again, given the results of the experimental proof of concept study, we can hold the photogrammetry measures to be a better approximation of the true cairn volume. A comparison to values with geometry shows the broad range of values and thus error that comes with more traditional approaches. The increased accuracy in both metric and volumetric measurement that comes from the adoption of this approach is clear benefit for documenting these features.

Cairn	***Lwh* (cube) m^3**	**$1/3\pi r^2 h$ (cone) m^3**	**$2/3\pi r^3$ (hemisphere) m^3**	**Photoscan m^3**
A	7.13	1.9	7.1	2.5
G	7.8	2.0	6.6	1.6
I	2.5	0.7	1.5	2.7
L	1.6	0.4	0.8	0.7
49SIT737	0.8	.9	1.8	1.1

Table 2-5: Volumetric method comparisons

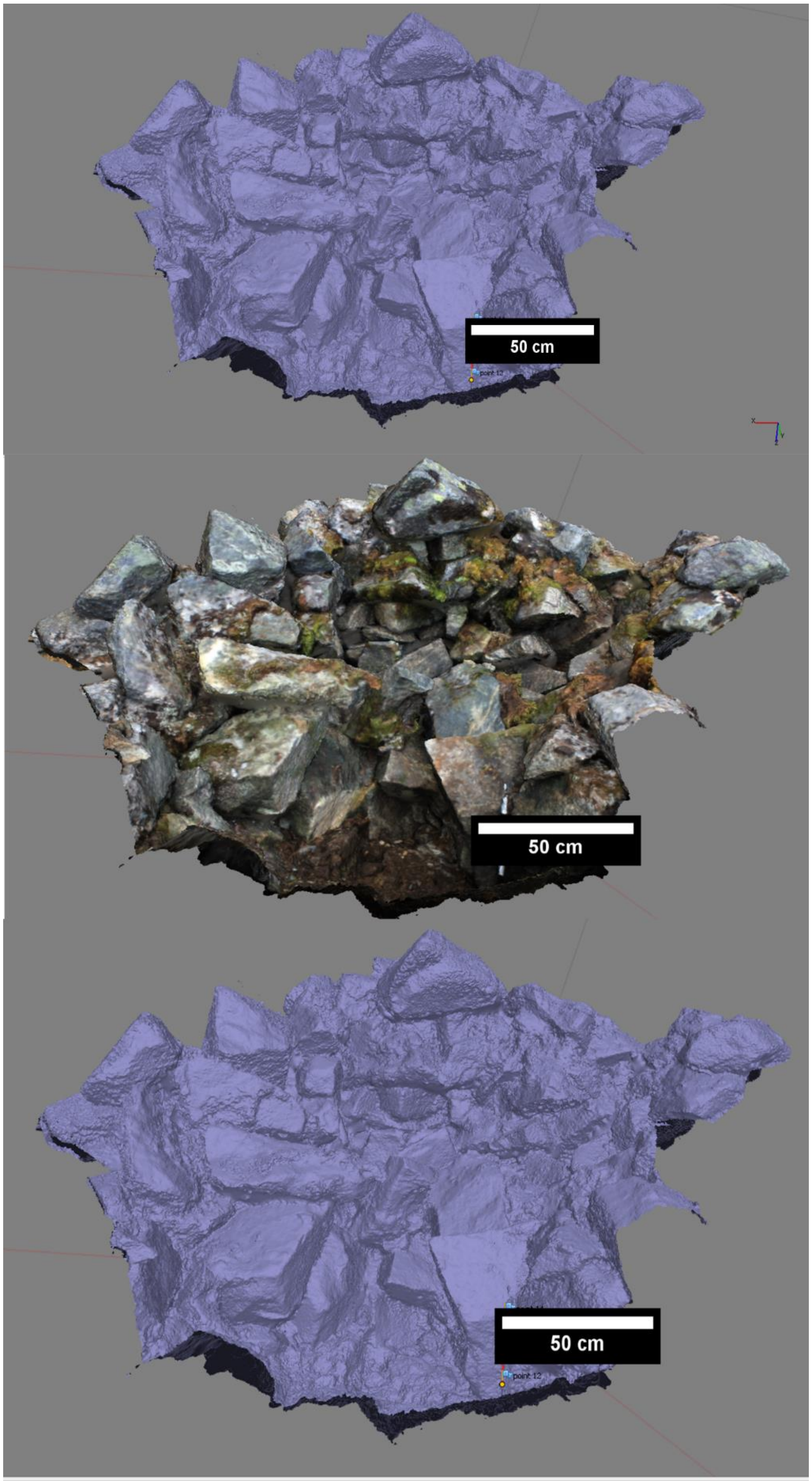

Figure 2-12: Excavated Profile view of Model of Cairn I from Baranof Island Displayed in Different Model Formats (both colored mesh and uncolored mesh) These scaled models present details on the nature of cairn construction and support further measurement in a 2D environment.

A final potential for this type of work, as demonstrated at Baranof, is to provide detailed excavation documents that support post analysis. As noted, several of the Baranof cairns were deconstructed in an effort to understand the function of these features and to look for datable materials that might provide an indication of their age. Here, before, during and after images were shot to produce models of each cairn. These models serve to document the deconstruction/reconstruction process, and also provide detailed scaled maps with which to record observations from the excavation. Figure 2-12 shows profile views in colored and uncolored mesh of cairn A following deconstruction. These detailed recordings provide clear scalable detail of exposed internal structure of cairns. The scaled models, and scaled 2D representations presented in figure 2-12 support additional analysis and provide more information and at a higher quality than regular field produced sketch maps. Line drawings and 2d image textured orthophotos based on these models can be quickly produced from images of models form any vantage. As previously noted, time in the field was limited to 10 days, so time spent on deconstructions was largely limited to the collection of samples and detailed field maps and other measurements were not completed. The ability to complete detailed measurement after the fact, thus enable more expansive research to be completed.

This work was completed in 2013 and subsequent updates have greatly increased the rapidity and accuracy with which models can be constructed. With current versions of PhotoScan, models made with low or medium settings can be rapidly completed using standard field grade laptops. With this advancement in the technology, models of cairns before deconstruction could be generated in the field (build times are generally less than 30 minutes with standard laptops) and would thus be available for aiding reconstruction efforts. As it stands in this project, the models produce throughout the cairn bisections provide a point of comparison to demonstrate that the integrity of the bisected cairns remains following our work and also serve as a baseline to monitor their ongoing preservation post analysis.

Discussion and Conclusion

The Baranof Island study presented here has demonstrated the suitability of photogrammetry for in-field feature documentation – particularly in remote areas where time spent in the field is minimal and the likelihood of regular visitation to sites is low. The larger cairn project represented the only detailed efforts to date to document these unusual and little understood features. Though time in field totaled 20 days, field conditions and inclement weather resulted in only 10 days of actual work documenting features. This attenuated schedule made the need for rapid documentation all the more pertinent.

The extreme nature and logistical demands of the cairn project provided an ideal test case for the technique’s ease of use, versatility and broad archaeological applicability. Here images for model production were obtained using existing gear within the course of regular field operations. The images for the models were obtained within the course of regular work with a minimum of preparation and features were documented as the crew encountered them during survey, and images for model building were obtained, before, during, and after the cairn bisections within the normal workflow of the deconstruction.

Because of time constraints, regular field mapping, drawing, and other more detailed field documentation had to be limited during the cairn survey. Most time within the short field season was limited to completing basic tasks of ensuring adequate survey coverage and completing cairn deconstruction/reconstruction. As a result, traditional field records consist of limited field photography and basic forms and field notes. The speed of photogrammetry image acquisition (generally less than 5 minutes per cairn), however, ensured that adequate documentation to produce suitable models was easily obtained. The models produced through this effort are thus all the more important as they represent one of the few sources of detailed, comprehensive, feature documentation from the study and thus support, continued observations and analysis in a post-field setting. The different model characteristics, detail, and ability to view models from all directions enable detailed post field examination in a way not possible with sketches and standard field photos, and certainly not possible given the limitations in field documentation for this project described above.

Beyond model quality and versatility, through the proof of concept experimental study, we have demonstrated the superiority of photogrammetry over more traditional approaches for metric documentation of feature dimensions and volume. Because of limited field time, only basic field measurements were taken, and the post-field analysis supported by scaled cairn models is thus all the more valuable to the project.

These factors support the utility of photogrammetry for applications such as the Baranof study reported here as well as a host of other field applications more generally. The straightforward nature of the process, from data acquisition to final model output means it can be easily incorporated into existing field and post-field work routines and likely represent a general time savings to more traditional techniques. The automation of most photogrammetry software packages requires limited expertise and can largely run using default settings. More importantly, models can be obtained under variable conditions as features are discovered, and no special equipment is needed. Existing digital field cameras and laptops can be utilized, and the software package is affordable or free with open source alternatives.

By far the greatest benefit of this process, however, is the increase in detail and versatility of photogrammetry models compared to traditional methods (e.g., profiles, sketch maps and photographs). The accuracy and precision easily achievable with this process is far superior to that typically obtained with traditional sketch drawing, while simultaneously providing photo realistic visualization of the object in 3D. Beyond this, the ease through which processed 3D models can be shared and manipulated presents a unique and versatile output format for both professional and public visualization (e.g., lectures, museum and outreach exhibits.) In the latter case, the quality of results and their visual appeal helps to increase public understanding and appreciation and thus represents a valuable means through which heritage can be brought to the public.

CHAPTER 3:

The application of 3D photogrammetry for in-field documentation of archaeological features: Two case studies from the Great Plains

Pedestrian survey comprises an important part of modern archaeological research practice. The ability to record and document archaeologically relevant materials over large areas is essential for establishing their spatial relationship across the wider landscape. However, the logistics of time efficient yet accurate documentation of archaeological features present a challenge to survey designs. In most cases, time is limited for in-field mapping, yet these records serve as a primary document for future decisions about significance, preservation potential, and long-term management.

Traditional sketch maps can achieve relatively high precision; however, in practice, factors such as time constraints and lack of expertise often limit the quality of results. Photography, on the other hand, offers greater overall detail, but issues of lens distortion require considerable preparation the analytical interest lies in the three dimensional properties of the feature, such as surface area and volume. More importantly, both approaches are limited to only presenting a fixed vantage on the subject of interest, and, thus, may not be suitable for addressing different analytical or conservation concerns in the future (De Reu et al. 2013).

The growing application of laser scanning in archaeology offers promise for the precise 3D documentation of archaeological features and the creation of data that are virtually manipulated. However, the use of these approaches at present falls largely outside the scope of most pedestrian survey projects. Aside from the relatively high financial cost involved, they tend to require a degree of expertise for data acquisition and processing, and thus are not well suited to many of the demands of archaeological field conditions, especially those encountered by mobile survey crews. Furthermore, the transportation, setup and data acquisition process involved in the use of 3D scanning technology often comes with considerable logistical and time demands. As a consequence, primary feature documentation during field survey is still largely accomplished with pencil drawing and limited photography.

The recent introduction of automated digital photogrammetry packages has provided a promising alternative to archaeological feature documentation (e.g., Barsanti et al. 2012; De Reu et al. 2013, 2014; Doneus et al. 2011). However, many of the studies on the technique's application in archaeology have focused on testing model accuracy and the optimization of results under the setting of academic research (e.g., Yilmaz et al. 2007; Remondino 2011).

In this study, we take a different research strategy by asking whether this approach can be suitable for use by non-specialists working within the constraints of field survey settings. Here, we present a study documenting the use of low-cost, off-the shelf, photogrammetry software for 3D feature documentation within the context of large-scale pedestrian survey. Using the case studies of pre-contact pit hearths in the High Plains of western Nebraska and historic architectural remains within the Chickasaw National Recreation Area of southern Oklahoma, we outline the use of this approach for (1) the detailed documentation of the 3D geometry of features from field photos, (2) the visualization of these features and associated quantitative data during the post-field management process, and (3) the visualization of archaeological heritage for both professional and public audiences.

It is important to note here that, the intention of this paper is not to present digital photogrammetry as a fail-proof approach that is independent of research design, nor is it to suggest that models created by regular crew members are apt to be of the same quality as those produced by experienced specialists. Rather, it is to demonstrate the utility of this approach as a viable addition or alternative to the standard approaches that dominate most field surveys. By demonstrating the types of results achievable with regular survey crews in the two case studies, we hope to outline the potential benefits of adopting this approach to a broad audience of professional archaeologists (also see McCarthy 2014).

Background

Archaeological Field Survey

Archaeological field survey has constituted a standard practice of research in North America since the latter part of nineteenth century. After World War II, salvage archaeology emerged as a result of increased large scale construction projects (King 1978). Field survey quickly became an essential first step in the archaeological assessment process, as well as a productive research technique for systematically documenting the distribution of past human activities within a given region (Dunnell and Dancey 1983; Heizer and Graham 1967; Schiffer et al. 1978). The use of archaeological survey has continued to expand, especially for compliance purposes (see Banning 2002 for summary). Today, most field surveys in North America are conducted within the context of Cultural Resource Management (CRM) (Banning 2002).

The principle aim of field survey is to discover, monitor, and document the location and distribution of archaeologically relevant artifacts, features, and sites over large areas (King 1978).

The design of field survey can vary markedly depending on the research goal, as well as the extent of the survey area, cost of time and personnel, and the expected return of archaeological information. In some contexts, features of interest are large and obtrusive, and thus identifiable through remote sensing (e.g., Chase et al. 2014; Crow et al. 2007; Doneus et al. 2008), while in other cases the spatial coverage of analysis is small enough to support the concentrated deployment of high power survey techniques, such as geophysical survey and 3D terrestrial scanning (e.g., Balzani et al. 2004; Guidi et al. 2009; Herrmann et al. 2014; Lerma et al. 2010).

Oftentimes, however, prior background information regarding the distribution of archaeological sites and features in the survey area may be more difficult to obtain. This can be due to the lower visibility or obtrusiveness of the features (Banning 2002), the spatial scale of the survey area, or simply due to lack of resources for extensive background research. Under these conditions, field survey may be designed to quickly record remains on an encounter basis within the course of broad areal coverage. In this context, achieving detailed documentation of archaeological features at the point of discovery remains a notable challenge. Namely, the level of detail achievable by traditional in-field methods is dependent on two key variables: 1) time and 2) personnel experience.

Techniques such as sketch maps require considerable field time to complete, and the degree of accuracy and precision is contingent on the amount of time spent on the documentation process. However, given that surveys tend to cover large areas, there exists a dilemma between the amounts of time invested in documenting individual features versus the level of survey intensity within a limited timeframe.

Traditional documentation methods are also heavily dependent on the experience and expertise of the survey crew. For example, the production of detailed and accurate sketch maps requires appropriate visualization, methods of measurement, and levels of precision.

A surveyor with illustration experience is capable of achieving sufficient detail and accuracy within a relatively short time period. On the other hand, maps produced by individuals with less or no experience are likely to be more prone to error. Because surveys often involve a large number of people with varying skill levels over a large area, quality assurance over the production of in-field sketch maps, therefore, becomes a potentially problematic issue. At one level, photography does provide a viable alternative to the manual documentation techniques because of its ease of use and the ability to capture great visual detail. However, issues such as perspective lens distortion mean substantial preparation and processing is required in order for photographs to provide useful measurements of the documented features. This is of particular concern if researchers are interested in obtaining dimensional properties of the feature(s) from the photographs.

Ultimately, both in-field mapping and photography are limited to documenting a fixed 2D vantage of the object. This limitation may not be much of an issue if the concern is over the immediate project goal, or that the documentation merely serves as preliminary data for further detailed studies. However, in cases where such survey results will likely to be used to address different analytical or conservation purposes in the future, or serve as primary documents for public education and outreach, the utility of traditional feature maps and photographs may become more limiting (De Reu et al. 2013).

Photogrammetry

Photogrammetry is the technique for deriving measurements from photographs. Based on the principles of trigonometry, photogrammetry relies on overlapping photographs taken from different locations. These photographs establish different "lines of sight" between each camera point and the object of interest. Through triangulating the intersections of these lines of sight, it is possible to determine the 3D location of the points of interest (Linder 2006). The introduction of computers during the 1960s enabled photogrammetry to perform more precise analytical calculations through the use of computational intensive numerical solutions and adjustment algorithms (Ghosh 1988; Schenk 2005). In the 1990s, the advent of digital photographs led to the replacement of films by digital images (Linder 2006). Along with the rapid development of storage device capacities and computational power, photogrammetric calculation is becoming a largely automated process with the capacity to handle large quantities of digital photographic information (Linder 2006; Schenk 2005).

The more recent development of "Structure from Motion" (SfM) approaches further contributed to the expansion of digital photogrammetry software packages available in the last decade. SfM operates by automatically solving the orientation and position of cameras without the need of *a priori* targets with known 3D positions (Fonstad et al. 2013; Westoby et al. 2012). Instead, these parameters are extracted by a redundant and iterative adjustment process that is based on features automatically extracted from large datasets of overlapping images (McCarthy 2014; Snavely 2008; Snavely et al. 2008; Westoby et al. 2012;).

This approach is suited to situations where images with a high degree of overlap capture the object of interest from multiple positions (Westoby et al. 2012). With minimal manual input, recent photogrammetry software packages are able to automatically orientate camera positions, match features, and generate complex dense 3D models. Since the introduction of these automated programs, studies have applied the photogrammetric technique to the documentation of archaeological sites, landscapes, features, and materials(e.g., Brutto and Meli 2012; De Rue 2012, 2013; Doneus et al. 2011; Ducke et al. 2011; Kersten and Lindstaedt 2012).

The goal of this paper is to demonstrate the potential utility and simplicity of digital photogrammetry for field survey practices that are commonly employed in CRM settings. The introduction and availability of automated photogrammetry packages has opened the possibility for individuals who are less knowledgeable of the technicalities to still apply photogrammetry with sufficient effectiveness. The technique provides a tool that may drastically decrease the amount of field time normally required for traditional documentation techniques, while at the same time providing comprehensive 3D feature models of visual and analytical quality that is equal, if not better, than traditional approaches. The flexibility and manipulatability of the 3D outputs also make photogrammetry a useful tool for promoting data sharing, public displays, and outreach. A variety of photogrammetry software packages exist on the market today; from open-source programs to proprietary packages that cost hundreds to a few thousand dollars (e.g., 123DCatch; Bundler; VisualSFM; PhotoScan; Vi3Dim). This paper is centered on the use of PhotoScan, developed by Agisoft1.

The Setting of the Two Case Studies

To demonstrate the suitability of photogrammetry for in-field archaeological feature documentation, we focus on two case studies centered on recent survey projects completed within the context of the University of Nebraska Archaeological Field School, one in the Oglala National Grassland (ONG) of far northwestern Nebraska (Figure 3-1) and the other in the Chickasaw National Recreation Area (CHIC) of South Central Oklahoma (Figure 3-2).Both projects employed a landscape approach where field crews document archaeological features dispersed across relatively large areas (e.g., Douglass et al 2015; Wandsnider et al 1995; 2008))

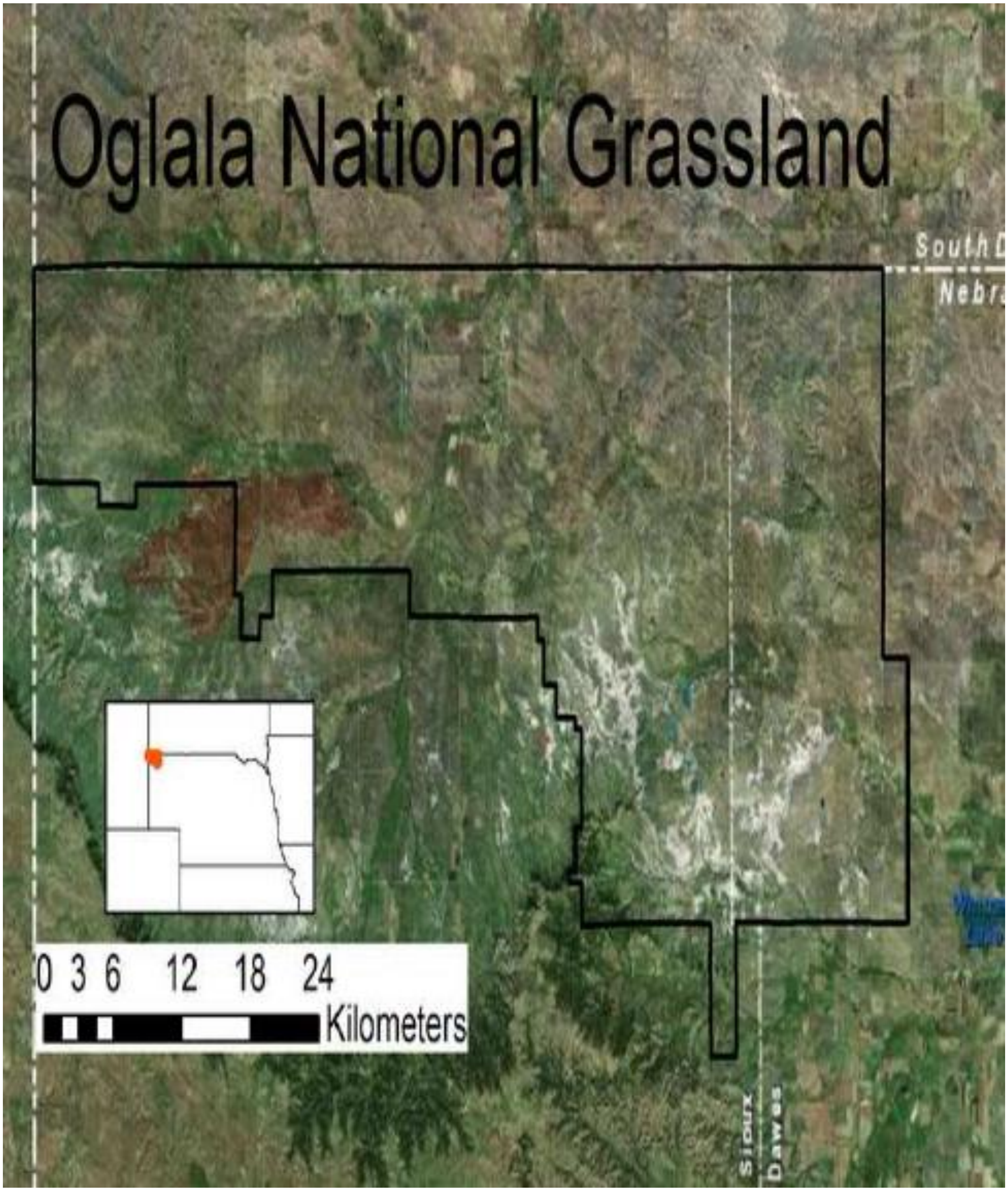

Figure 3-1: Map of the Oglala National Grasslands, Northwestern Nebraska

Figure 3-2: Map of the Chickasaw National Recreation Area, South-central Oklahoma

Pit Hearth Features in the Oglala National Grassland

Ongoing survey in the ONG has documented the occurrence of pre-Euroamerican contact pit hearth features throughout the study area. These remains provide a unique opportunity for chronological control in a region where few detailed excavations have been completed. Ethnographic accounts (See Wandsnider 1997 and references therein) indicate that these features likely functioned as ovens where the sediment matrix of the hearth walls and added rock elements served as heat storage thus enabling sustained temperatures over prolonged periods of time.

In the study region, feature discovery is largely limited to erosional contexts, where the pit hearths are identified as u-shaped features (averaging 1 meter in depth and 75 centimeters in diameter (Wandsnider 1999) within the exposed sedimentary profile, often accompanied with clusters of heat-retainer stones at their base. Because the discovery of these features is largely a function of geomorphic exposure through erosion, they are always in a precarious position for long-term preservation. For this reason, quality and comprehensive documentation is of the utmost importance, and efforts must be made at initial discovery to assess their likelihood for long-term monitoring vs. salvage efforts.

Sulphur Springs, Chickasaw National Recreation Area

Between 2013 and 2014, archaeological survey has been completed at CHIC through a joint project between the National Park Service and the University of Nebraska-Lincoln. The primary goal of this project was to assess archaeological remains within the park with particular emphasis on exploring the archaeological signature of the area’s transition from historic town to national park. The original town was founded while Oklahoma was still classified as Indian Territory and reflects a haphazard organization in proximity to a number of local springs. These springs were prized for their medicinal purposes and were the focus of recreational activities in the immediate area. In time, the town's proximity to the springs spurred concerns about sanitation and pollution and the original town plot was eventually purchased for the development of a national park. The buildings and adjacent houses from the original town were then either destroyed or relocated (Hohmann and Grala 2004 and references therein).

Survey for the remnants of historic structures, mostly in the forms of depressions, foundations, and building rubble, was conducted in the spring and summer of 2014. The large areal extent of the project, the difficulty of the dense wooded environment, and the potential detail contained in individual features (e.g., block walls, wells, building rubble) presented a challenge to detailed feature documentation.

The conditions of feature discovery, the aerial extent of the study area, and the relatively rapid pace of survey for both the ONG and CHIC projects present a unique context for exploring the value of photogrammetry. In both situations, budget, terrain, and scale precluded the use and transport of bulky and expensive equipment (e.g., terrestrial laser scanners) in the course of regular field survey, while at the same time, the expertise and time demands necessary to complete highly detailed line drawings were also lacking amongst crew members. Finally, in both cases, archaeological features (i.e., hearths and building remains) are of primary interest to public outreach and interpretation, and the ability to display 3D information is of particular relevance to highlight heritage to the interested public. Thus photogrammetry offered great potential both as a means of expediting feature recordation and as a tool for public display of heritage.

Methods

The photogrammetry program used for both projects was the PhotoScan software package developed by Agisoft LLC (AgiSoft LLC 2014a: iv). The software operates on Windows systems and utilizes a wide range of image file types (JPEG, TIFF, PNG, BMP, and MPO) to create 3D meshes and textures. While the software is highly automated and thus performs admirably on default settings, there are also a multitude of options where the user may control the input parameters for model generation. For example, individual photographs (called “cameras” in the software) can be custom enabled or disabled in the process of mesh construction; “masking” tools can be employed to limit the portions of an image used in the process; and control points can be established for georeferencing and scaling the model. The workflow of PhotoScan as with other packages proceeds in two general steps, in-field image collection and in-office data processing.

Image Collection

Data acquisition is the only stage of the process that necessarily takes place in the field. This step is executed by gathering a series of conventional photographs of the archaeological features, taken with standard digital cameras and lenses. For this study, we used a Canon Rebel Xsi digital single-lens reflex (SLR) camera with a EF-S 18-55mm zoom lens; though the software is capable of generating a workable model with cameras covering the gamut from cell phone camera to high end professional grade SLR cameras(e.g., Doneus et al.2011; Kim et al 2013) .

The 3D reconstruction of a ‘scene’ (the term herein denotes the item or feature that is of interest to the archaeologist) requires that photos of the target object are taken from different vantage positions thus allowing the reconstruction of geometry. Photographs should be organized in such a way as to capture the scene from multiple angles with sufficient overlap. The number of photos required to obtain a desired result will vary, but at a minimum the reconstruction of any given area in the scene requires that it be observed in three images. As digital photographs are easy to acquire, the practice adopted here was to obtain many photos with duplicates thus ensuring adequate capture of all areas. This also eliminates the risk of not being able to complete a model because of user error for individual shots. Redundancy can then be reduced prior to model production, though the speed of model generation in general is such that higher numbers of images can be incorporated.

Different strategies for photo capture should be adopted depending on the morphological structure of the object of interest (see AgiSoft LLC 2014a:5-6). For a single surface feature (façade), individual camera positions should be spread out across the object (Figure 3-3a).For isolated features with multiple surfaces, individual cameras should be positioned around the feature with converging vantages (Figure 3-3b).

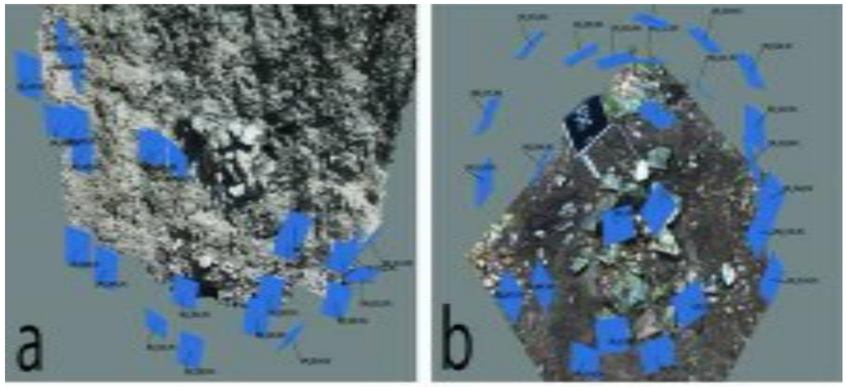

Figure 3-3: Examples of camera placement for two types of features. The left image (a) depicts a façade feature (hearth) exposed on an eroded cut-bank. The right image (b) shows an isolated architectural feature on the ground. The blue rectangles represent individual photographs and their respective camera positions.

There are a number of factors to consider when obtaining pictures. Strong shadows should be avoided if possible with ideal conditions being bright but overcast days. Morning light is also good for providing quality images for model generation. However, these are idealized conditions. Models generated in this study were shot when features were encountered, and satisfactory models were obtained even when conditions did not meet the ideal.

Another aspect to consider are obstructing objects and other elements that may create variance in the scenes shared between shots. These include moving objects (e.g., blowing grasses and brush, clouds, members of the field crew) and reflective surfaces, such as wet surfaces. The use of flash can also create inconsistency in the lighting among photographs.

Other camera settings such as ISO, shutter speed, and aperture should also be adjusted accordingly to reduce the amount of blurring and noise in images. While these elements of error should ideally be avoided, the affected areas on photographs can also be effectively removed through the “masking” function during processing.

For the purpose of linking models to known geographic locations, ground control points can be included in the photographs to provide objective 3D georeferencing. In the field, these ground control points can be acquired using GPS or a total station. Scaling of the model, however, only requires that the distance between two identifiable points in the scene be known. This can be achieved by measuring the length of prominent features or by incorporating an object of known size into the scene (e.g., scale bar). Within PhotoScan, markers can then be positioned on these points in the finished model and the distance entered to give the model scale.

Data Processing

Using PhotoScan, 3D models can be generated in a fully automated four step workflow: (1) the orientation (termed ‘alignment’ in the program) of photographs, (2) the calculation of a point cloud (a set of data points representing the external surface of the object of interest in a three dimensional space), (3) the generation of a 3D mesh surface from the point cloud, and (4) the generation of a texture map for the 3D mesh using photographs. The recommended computer setup by the software package involves a 64-bit operating system and a high-end graphics card (AgiSoft LLC 2014a). However, the data processing steps can also be completed on a standard utility grade computer. For the purpose of this study, we opted to use existing field laptops already on hand. We did this in an effort to consider the utility of our approach to a broad audience of users who are potentially lacking high-end professional grade equipment.

Prior to orienting photographs, it is useful to evaluate image quality. Images that are blurry or unfocused should be removed. Other unwanted areas within each photo can be further excluded by pre-processing each image with the “mask” function in the software. These undesirable areas include those that are unfocused, are largely uniform with no distinct landmarks, and objects that have moved locations between the times when the photos were captured. The same process can be done to eliminate image areas that are not relevant to the scene of interest, such as the background landscape (Figure 3-4). This can shorten the processing time and lower the required amount of RAM.

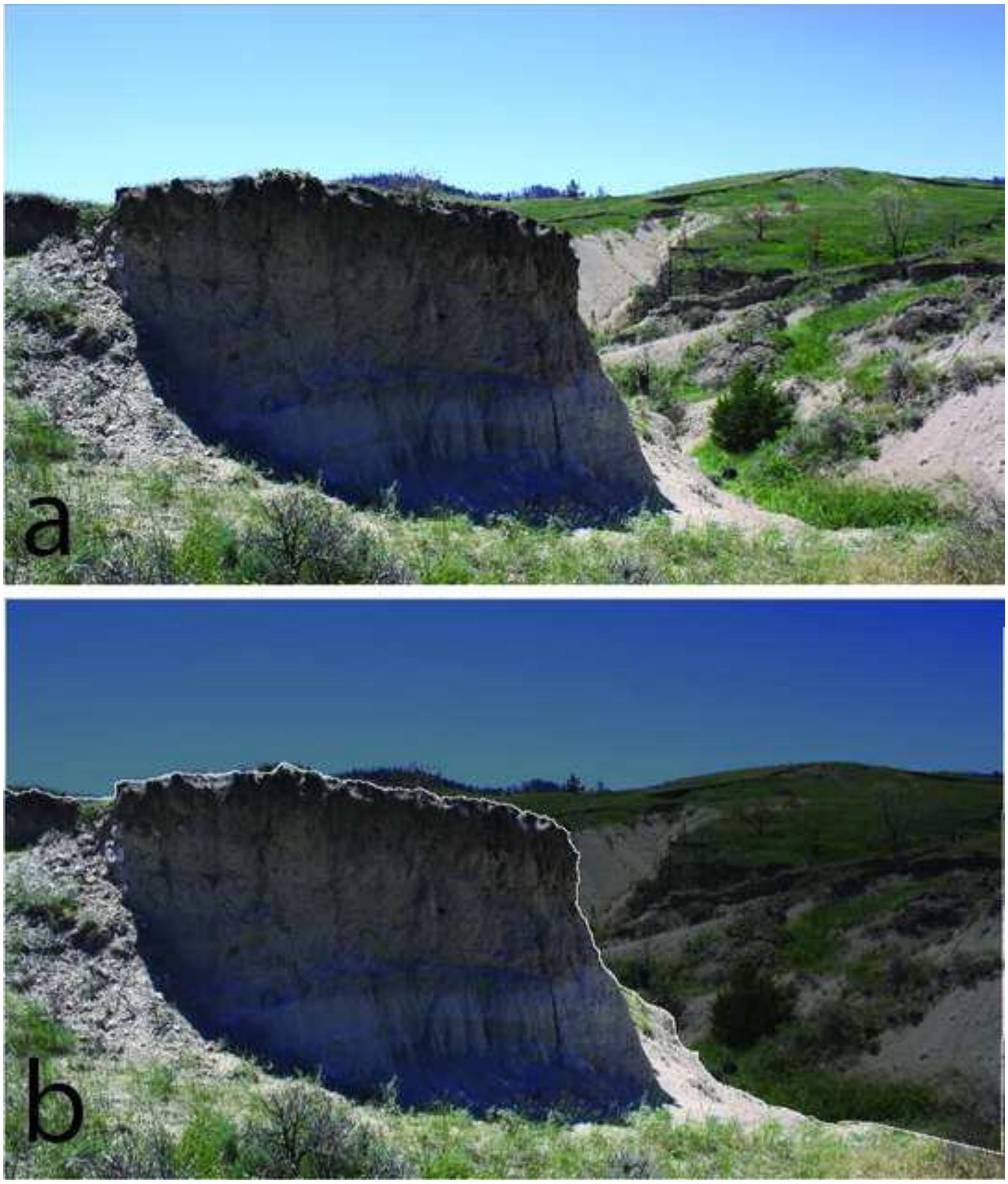

Figure3- 4: Masking out areas within an image. Top image (a) shows the original photo; bottom image (b) shows masking of the landscape background not desired in the final model. This process cuts processing time and helps to isolate the scene after alignment.

After pre-processing of the images, the first stage in model generation is the orientation of the photos with respect to the desired scene. PhotoScan does this through the SfM technique described earlier, which computes 3D information by interpreting scene geometry from image sequences captured by moving a camera around a target object (Ullman 1979). Here, the SfM algorithms detect feature points (e.g., object edges and specific details) and then track the movement of these feature points throughout the image sequence. Through this process, the software orients the camera position of each photo within a 3D space, and builds a sparse point cloud based on the triangulated feature points in the scene of interest (Figure 3-5A).

This first step is the primary basis from which the final model gains its accuracy, so the point cloud and camera orientations should be visually inspected at this stage to identify errors. The program offers low, medium, and high settings for this step, mainly affecting the accuracy of the estimated camera position; though the speed and processing demands of this step allow for the use of the high setting in almost all instances. Further processing with the gradual selection function can also be used to control the accepted error range for the points within the point cloud (vertices). In addition, any of the resulting points that are unneeded can be manually deleted using a variety of selection tools, or the bounding box can be resized and positioned to constrain the area that gets used for further model making.

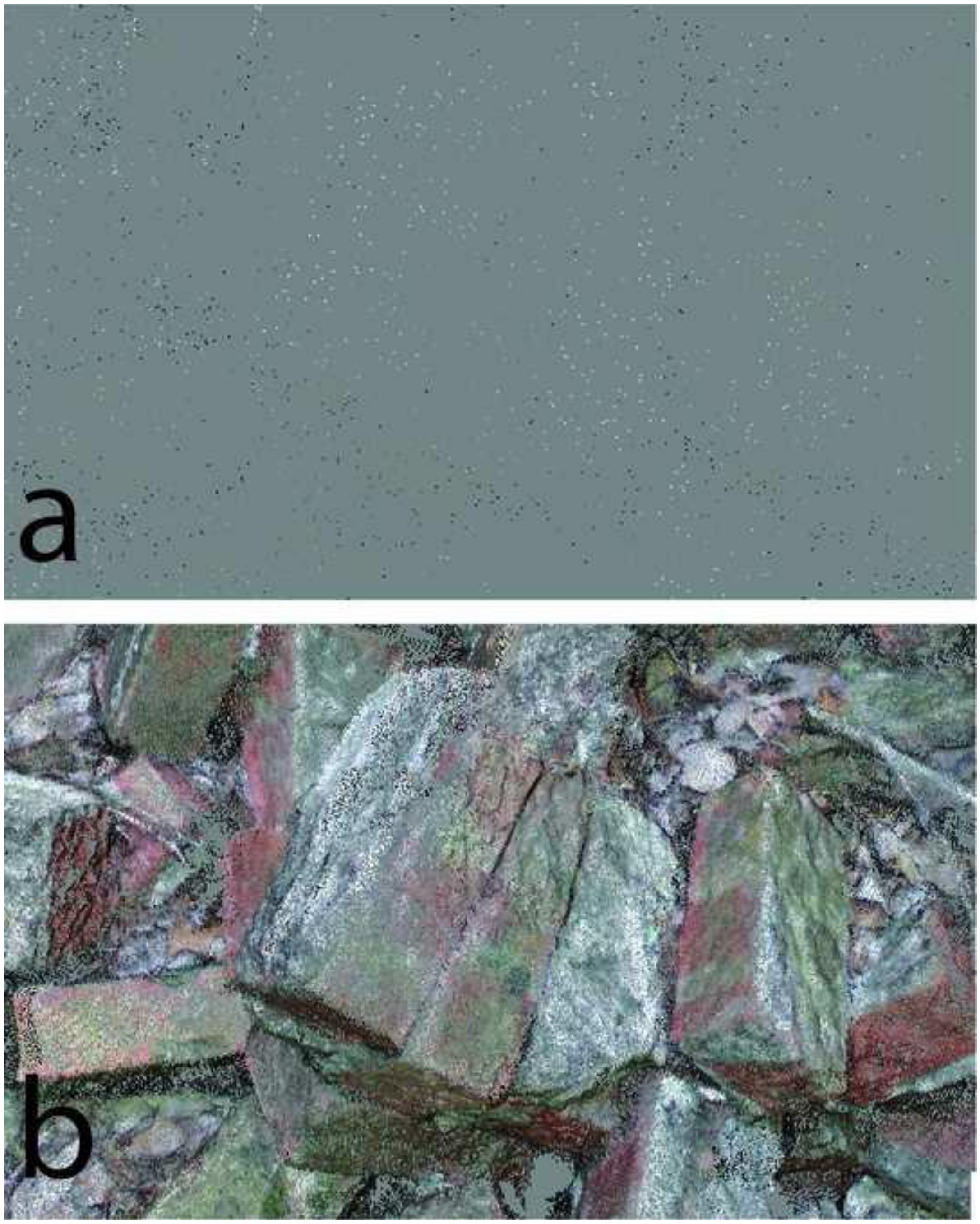

Figure3- 5: Brick feature demonstrating differences between (a) sparse point cloud and dense point cloud (b).

The second step involves the construction of a dense point cloud from the sparse point cloud (Figure 3-5B). The software does this through automatic image matching algorithms and computes the 3D coordinates of many more points from pairs of oriented photos

Again, a selection of quality options (low, medium, high, and ultra-high) is available. Each increase in setting detail produces a denser point cloud, but also adds considerably longer processing time and is more intensive on computational resources. With utility grade laptops, such as were used in this study, scenes with large numbers of photos can fail to complete the dense point cloud under the high quality setting. Therefore, the medium setting was used for the majority of models in this study.

In the next step, a 3D polygon mesh is built from the dense point cloud. Here, the software uses image matching algorithms to generate a 3D mesh based on matched pixel locations within the image scene which can be visualized as solid, shaded, and wireframe modes (Figure 3-6).

The mesh is, in essence, composed of numerous triangular surfaces (faces) made on sets of connected vertices within the point cloud. For the shaded mode, the color of each vertex is calculated as an average of the pixel values from the corresponding location in the images. The accuracy of this color interpolation of the model increases with the level of model detail (i.e., higher number of faces).

In this study, the qualities for dense point cloud and 3D mesh were set to be matching for all the models generated (i.e., if a model is run on high quality for dense point cloud creation, its 3D mesh is also processed with the high quality setting in terms of polygon count). This is done to provide a general comparison between different model qualities while maintaining a reasonable processing timeframe for model generation; though we recognize that the interaction between settings of the modeling stages becomes confounded and would require further investigation in order to evaluate the range of variation obtainable.

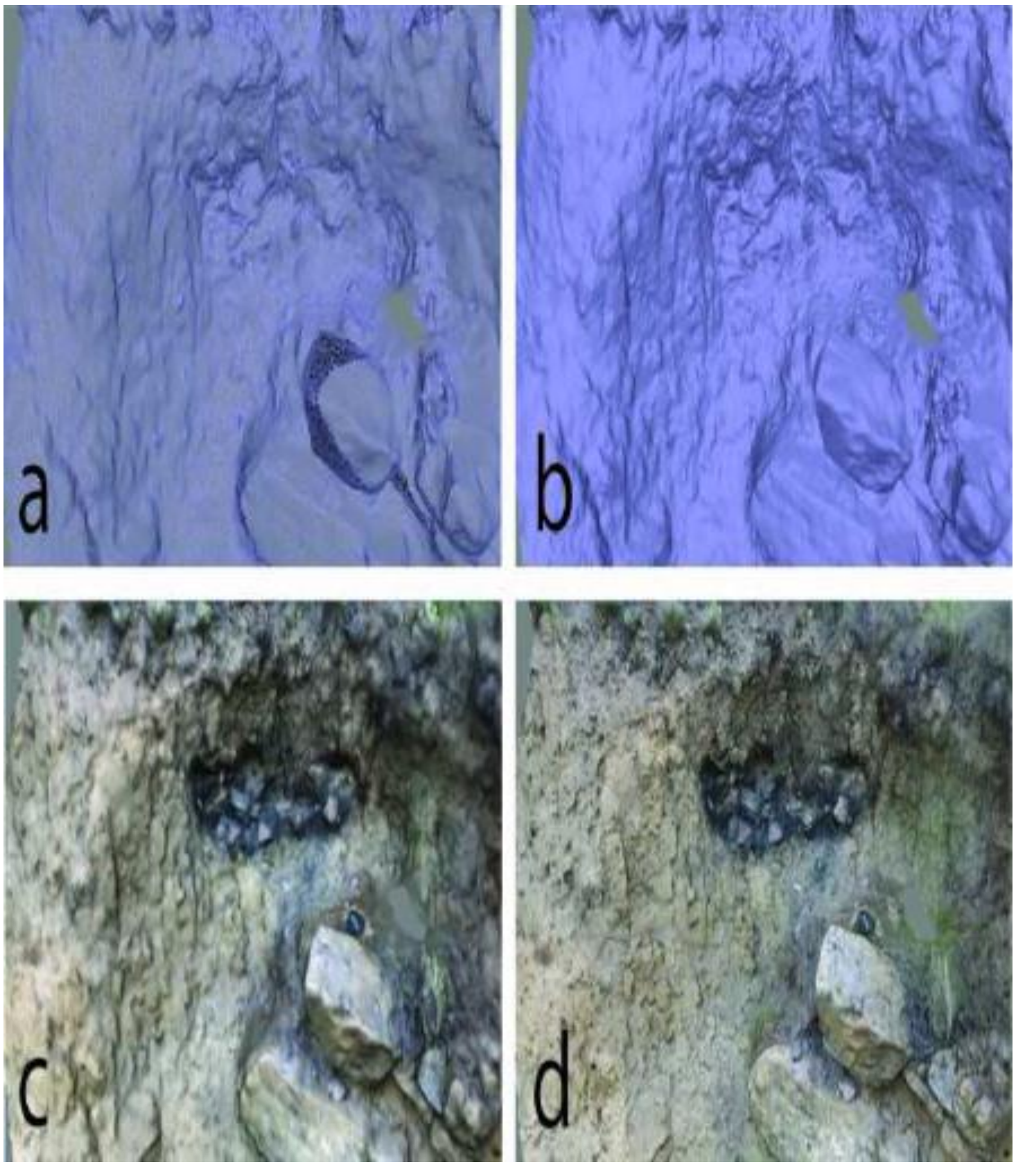

Figure 3-6: Model of hearth feature in the forms of (a) wireframe, (b) solid mesh, (c) shaded mesh, and (d) textured mesh.

Within all steps from orientation to building the mesh surfaces, the higher the accuracy and quality setting used in the program, the higher the detail of the model geometry, but also the greater the demand on computer memory and computation time. In our experience, we have found that photo orientation can be completed on high even for preliminary field testing, but that the dense point cloud and mesh building steps are typically limited to low and medium settings for laptops. With higher-end laptops and computers, models using high settings have been produced, but the process takes significantly longer to complete.

A final step enables the generation of a more realistic texture for the 3D mesh based on mapping one or more of the source images onto the 3D model. Settings available at this stage are average and mosaic. The creation of the texture map is an optional step and does not affect the geometry of the model, but is of benefit both for visualization and inspection of photo details in a 3D space, and is also useful for identifying the location of reference points for georeferencing or determining the scale of the model in post-processing. Unlike laser scanning and other digitization techniques, model scaling is not built-in for photomgrammetry since photos do not share a uniform scale. The generated 3D model is instead scaled by inputting a known distance between two landmark points within the model (this function is only available in the professional version of PhotoScan) (AgiSoft 2014b 46).

Finally, PhotoScan has a number of output options for 3D and 2D visualization. Accurate 2D portrayal of the model for subsequent measurements on paper can be achieved using the orthophoto options while 3D options include the export of a digital elevation model, a point cloud, or the model itself in various file formats, including PDF.

PhotoScan also supports direct posting of 3D models online through the use of a number of web services.

Results

Though multiple models were made in this study, results presented here are organized to demonstrate: (1) model characteristics that look at variation in the models in terms of the detail of model attributes (2) model presentation of the 3D models in comparison to traditional approaches such as feature sketch maps, (3) consideration of accuracy of the models generated with reference to feature dimensions measured in-field, and (4) usage for visualization to monitor preservation, and for public/professional dissemination of results.

Model Characteristics

Two examples are used to explore variation in model characteristics under different resolution settings. The first is an excavated hearth feature from the ONG. The second is an architectural foundation feature from CHIC. For the first feature, photos were input without processing; for the second, some moderate masking was done to remove irrelevant items and background noise such as trees and branches. Three sets of models with quality settings of high, medium, and low (for both dense point cloud and mesh construction) for the two features are shown in Figure 3-7. The models show visible differences in mesh detail, namely in terms of surface texture and vector color. These differences are largely dictated by the resolution of the dense point cloud and the number of polygons in the resulting 3D mesh.

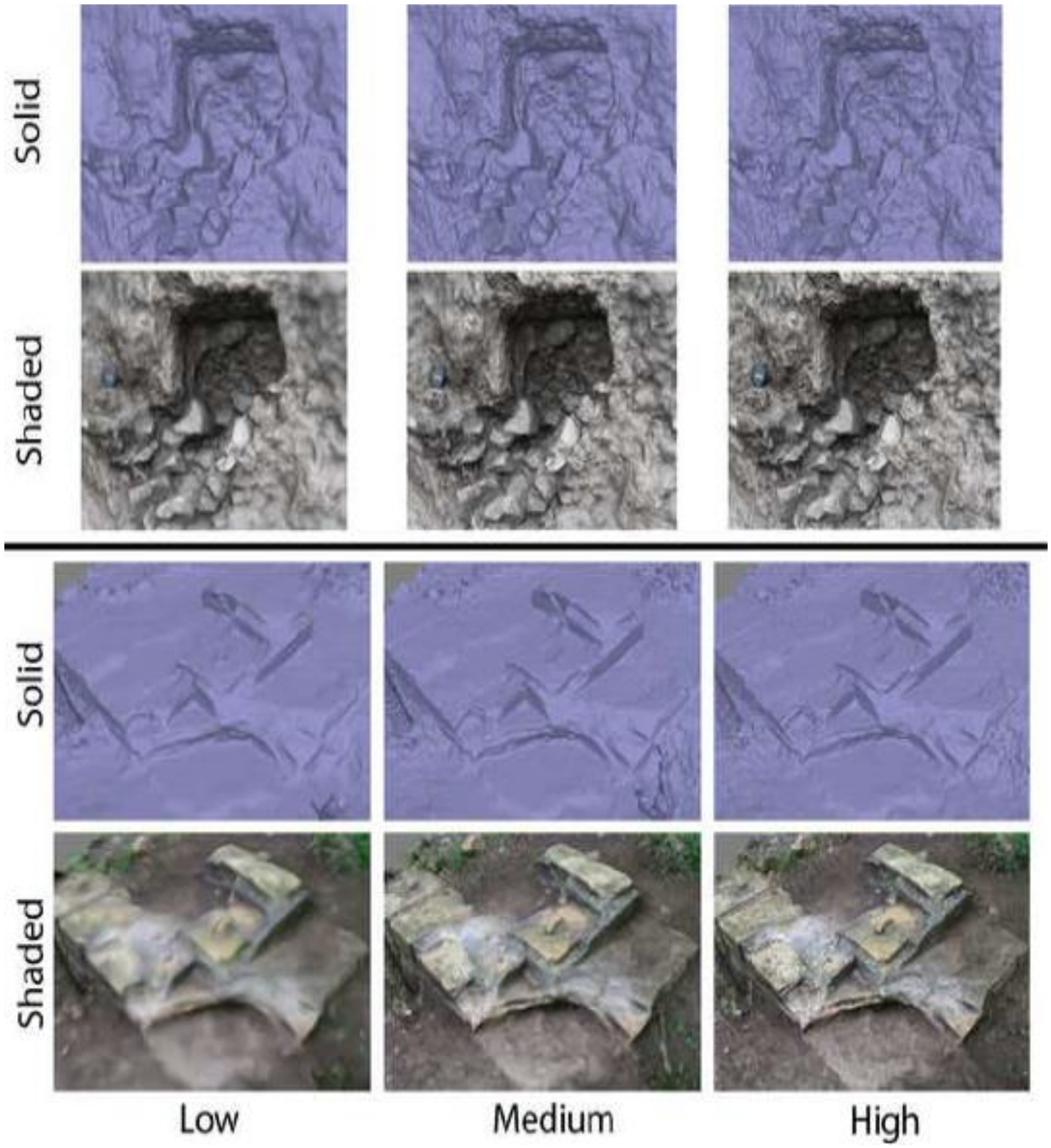

Figure 3-7: Solid and shaded meshes created with low, medium, and high settings (for both dense point cloud and mesh generation). The top set represents an excavated hearth in Oglala National Grassland; the bottom set represents an architectural foundation feature from the Chickasaw National Recreation Area.

Model Presentation

Figure 3-8 demonstrates the use of a 3D model of an excavated well feature to construct a profile map with planer and cross-section perspectives. Each view is projected orthographically and thus allows measurements to be made with the scale bar. Because the feature was only half excavated, the latitudinal cross-sections were established in relation to the excavated area as opposed to the entire feature. This approach allows accurate, quick and relatively easy measurement of objects in the model. More importantly, since photo documentation is part of most feature documentation routines, this method reduces the amount of field processing time required for traditional mapping, and instead provides a relatively effective yet inexpensive means for producing high quality feature maps that can be explored and analyzed three dimensionally from different perspectives. Time savings can thus be invested in other forms of feature analysis (e.g., sediment analysis and description)

Figure 3-8: Plan view map of an excavated well (made with 34 photos) from the Chickasaw National Recreation Area.

Figure 3-9 compares typical feature maps made with graph paper and meter tapes with digital outlines overlaid on planer orthophotos of the corresponding models. The digital outlines were completed via computer using orthophotos from the finished photogrammetry models. The comparison shows that standard tape recording procedures can produce maps with relatively high accuracy and precision, particularly when done by experienced personnel and with sufficient field recording time; though they are also more prone to human error due to inconsistencies and subjective perceptions during the recording process. Instead, the greater accuracy and efficiency of the digital sketches makes the approach a superior alternative for feature presentation. Both field-drawn maps presented here each required over two hours of in-field recording to complete. The field time for photo acquisition, on the other hand, was less than a few minutes. The addition of processing time for the 3D models does bring the combined total for map completion more in line with each other; however, because processing is largely automated, other tasks can be completed during these steps, meaning the amount of active human participation in map construction becomes minimal.

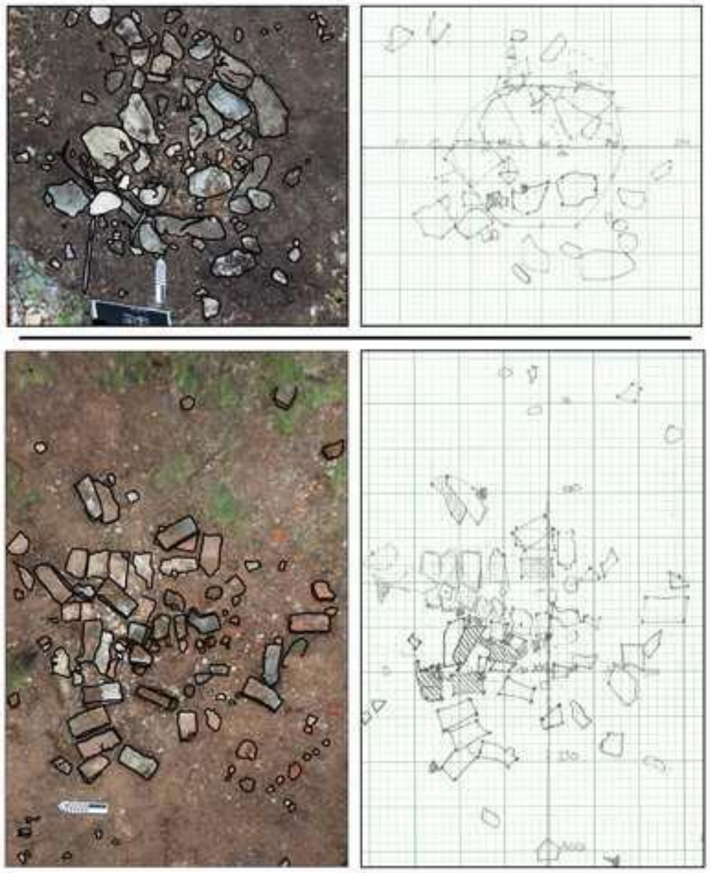

Figure 3-9: Comparison of digital sketch maps produced from orthophotos with in-field feature maps of a historical unexcavated well (top; made with 26 photos) and a cluster of building rubble (bottom; made with 34 photos).

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Figure 3-10: Orthophoto landscape map showing the location of a hearth (model made from 156 images).

Figure 3-10 shows the ease with which large scale models capturing the broader setting of a feature can be generated. Here we have a cut bank with exposed hearth element. The detail far exceeds the types of sketch maps that accompany most field forms and is generated quite quickly. Furthermore, the manipulability of the model in 3D view allows it to be viewed from multiple angles and thus aids in the relocation of features in subsequent surveys. In the case of pit hearths in the ONG, the location of these features is often difficult to identify even when guided to the general area with GPS coordinates.

This is because the broad uniformity in landscape features, such as cut banks, and differences in lighting makes them difficult to differentiate unless viewed from vantage angles and distances that are similar to those associated with the original photographs. 3D models that are manipulated via laptops, tablets, and smart phones thus can provide an invaluable aid for relocation and also provide a vantage onto the broader context for preservation consideration and monitoring.

Consideration of Model Accuracy

Figure 3-11 depicts a scaled model of masonry remains from the residence of a prominent community member of the historic town of Sulphur Springs. Yellow dots in the model depict reference points while red lines denote distances between markers. The model was scaled using a known distance on the feature as obtained through manual measurement in the field. Subsequent field measurements of additional feature elements were also made for comparison with those obtained using the scaled model.

Table 3-1 compares distances made from the scaled model to those obtained in the field with subsequent deviations between the two. What is clear from these results is the high level of agreement between the two sets of measurements. It should be noted that discrepancies cannot be attributed to inaccuracies within the photogrammetry generated model as field measurements were taken using standard meter tapes and thus cannot be held as truly known values. Further refinement in the field measurements using an EDM or other approaches with greater precision would likely produce even tighter correspondence between model and field measurements. Regardless, these results demonstrate the close agreement of measurements made from models with those made in the field and the suitability of the model for allowing accurate measurement of additional feature elements during the post-field process.

Figure 3-11: Scaled architectural feature map showing masonry remains from a prominent residence in the historic town of Sulphur Springs (model made from 61 images). Yellow points denote markers while red lines denote distances measured from the model. Note that what is calculated here is the straight line distance between two marker points in a virtual 3D space. Thus, as shown in the figure, the measured line

may in fact "cut through" other features, and hence cannot be viewed to be directly comparable to in-field measurements taken from calipers and tape measures.

Marker1	Marker2	Modelled distance (cm)	Manual distance (cm)	Error
13	14	89.7	90	0.33%
29	30	22.9	22.3	-2.92%
27	28	42	39	-7.69%
17	18	11.6	11.2	-3.85%
23	24	17.1	16.5	-3.64%
29	32	58.5	56	-4.46%

Table 3-1: A comparison between modelled and manually measured distances from an architectural feature within the Chickasaw National Recreation Area.

Usage for Visualization

As noted, PhotoScan supports the export and uploading of models in a number of 3D formats that provide further benefits for model visualization. 3D PDF models (Appendix B) represent one output format that is particularly versatile for further field use and model sharing. These models, though decimated to decrease file size, retain considerable model detail within a file format that is readily accessible and easily manipulated without costly software all while maintaining file sizes that are generally suitable for sharing via email (i.e., less than 20 MB). Other formats (e.g., OBJ) enable the export of the fully detailed model that can then be viewed using a variety of proprietary and open source software packages (e.g., Meshlab). Finally, the option to upload models directly to online model hosting sites (e.g., Sketchfab) presents a fast and easily accessible option for both public and private display.

To demonstrate these formats, example models from the ONG and CHIC projects have been made available through supplemental data and through Sketchfab (https://sketchfab.com/unlarchaeology/models). These outputs options are ideally suited for digital archiving and for further analysis and examination following field work and also represent a convenient and versatile option for presentation to public and professional audiences.

Discussion and Conclusion

Through this study we have demonstrated the suitability of photogrammetry for in-field feature documentation. The raw data (digital images) for the models were obtained in the field using a minimum of preparation, and the time of acquisition was in fact much faster than traditional profile and sketch mapping. Processing of these data has demonstrated, through a number of different modeling options, the precision and versatility of this approach and its suitability for use with standard utility grade cameras and field laptops.

A major benefit of the recent photogrammetry software packages is the straightforward nature of the process, from data acquisition to final model output. In-field data acquisition is easily incorporated into existing field protocols and likely represents a general time saving procedure compared to more traditional manual methods of feature mapping.

Largely as a result of the automation of workflow, the post processing of models requires limited expertise and can largely run using default settings. In contrast to laser scanning, this process can be executed by field and lab crews with minimal specialized training all while providing a generally comparable final product (also see McCarthy 2014). More importantly, models can be obtained under variable conditions as features are discovered, and no special equipment is needed. Existing digital field cameras and laptops can be utilized, and the software package is affordable or free with open source alternatives.

Even when manual methods are retained, this study demonstrates that photogrammetry likely represents a beneficial addition to existing field protocols and may serve as an initial warrant for more detailed study at a later date (e.g., decisions to complete more intensively designed photogrammetrical or terrestrial laser scanning surveys may be predicated on more basic models developed at the point of initial discovery). As image acquisition is cheap and time efficient, expanding field photography routines to include images gathered from enough angles for sufficient models to be generated is feasible and beneficial under most field conditions. Whether models are regularly generated or not, the ease of image storage means that photogrammetry can provide additional detail that could be of use for future study. This is especially true for large scale surveys where features and other points of interest need to be documented quickly but accurately for future off-site comparison.

By far the greatest benefit of this process, however, is the increase in detail and versatility of photogrammetry models compared to traditional methods (e.g., profiles, sketch maps and photographs). The accuracy and precision easily achievable with this process is far superior to that typically obtained with traditional sketch drawing, while simultaneously providing photo realistic visualization of the object in 3D. Beyond this, the ease through which processed 3D models can be shared and manipulated presents a unique and versatile output format for both professional and public visualization (e.g., lectures, museum and outreach exhibits.) In the latter case, the quality of results and their visual appeal helps to increase public understanding and appreciation and thus represents a valuable means through which heritage can be brought to the public.

CHAPTER 4: CONCLUSION

This thesis consists of two thematically related, journal quality articles written with the purpose of reporting on field experiments with non-traditional forms of photogrammetry under variable field conditions. This thesis as a whole has demonstrated three principles findings 1). Photogrammetry can be used to rapidly produce detailed 3D documents of sites and features, 2). The use of these models enables accurate linear and volumetric measurements during post field analysis, and 3). Utilizing models for the purpose monitoring long-term preservation and outreach presents an advancement on the techniques that are currently available.

In-field photogrammetry was used to document rock cairns in remote Alaska, eroding pit hearths in western Nebraska and excavations and building foundations in Oklahoma. This new technology allowed for a greater level of in-field documentation at an expedited rate when compared to traditional field maps.

Linear and volumetric analysis was conducted on models produced from photographs taken in the field and models produced in the field gaining a greater insight and understanding of the features being examined and in greater detail than traditional calculations and measurements.

Models produced in three-dimensions can capture the fourth- dimension, time, and can be utilized to a higher degree than traditional photographs and sketch maps in understanding dynamic environments and their impact on features such as the pit hearths in western Nebraska where volumes and linear degradation can be measured season-to-season through the use of easy to capture digital photographs and three-dimensional models produced by PhotoScan by Agisoft.

With a continually diminishing learning curve and increased accessibility, the use and adaptation of photogrammetry and PhotoScan to archaeological field methods and surveys will become standard practice and supplement sketch maps and photographs in a manner to aid in data collection of site and feature data.

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Appendix A: Concept Cairn Tables

Concept Cairn 1

Rock	Length(mm)	Width (mm)	Height(mm)	Volume(cm³)
R1-C1	**120.8**	**85.6**	**40.5**	**190**
R2-C1	**114.6**	**79.5**	**51.5**	**200**
R3-C1	**93.0**	**87.3**	**52.0**	**175**
R4-C1	**119.1**	**96.5**	**68.2**	**310**
R5-C1	**109.8**	**104.5**	**67.1**	**275**
R6-C1	**98.3**	**86.4**	**56.4**	**120**
R7-C1	**107.5**	**97.2**	**50.6**	**140**
R8-C1	**86.1**	**66.2**	**42.2**	**120**
R9-C1	**117.9**	**77.5**	**58.2**	**260**
R10-C1	**85.2**	**74.3**	**44.8**	**120**
R11-C1	**104.8**	**93.9**	**61.2**	**270**

Concept Cairn 2

Rock	Length(mm)	Width(mm)	Height(mm)	Volume (cm³)
R12-C2	157.7	101.9	61.3	375 cm³
R13-C2	96.6	65.8	57.5	140 cm³
R14-C2	112.7	78.2	41.1	90 cm³
R15-C2	115.5	90.7	75.1	405 cm³
R16-C2	89.3	69.3	60.9	50
R17-C2	92.9	88.7	41.5	120
R18-C2	103.2	72.5	62.3	265
R19-C2	145.2	126.1	73.7	610
R20-C2	180.1	104.1	79.5	810
R21-C2	103.0	95.6	74.8	240
R22-C2	166.7	103.4	81.3	440
R23-C2	122.5	111.2	60.1	400

Concept Cairn 3

Rock	Length(mm)	Width(mm)	Height(mm)	Volume(cm^3)
R24-C3	103.2	61.0	58.3	210
R25-C3	112.8	89.1	60.3	290
R26-C3	136.0	83.3	77.6	395
R27-C3	103.2	70.9	54.2	200
R28-C3	92.9	86.0	40.8	130
R29-C3	126.9	77.5	54.1	290
R30-C3	91.0	83.8	51.1	195
R31-C3	128.3	96.3	82.9	395
R32-C3	82.3	78.0	59.1	275
R33-C3	107.0	94.5	50.1	300

<u>Appendix B: Cairn Models</u>